4/16/64

CON[redacted]
RE[redacted]TA
A[redacted]omic Energy [redacted]

C66-22333

Astronuclear
WANL-TNR-095

APRIL 16, 1963

NASA CR70668

SUBMITTED BY:

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh 36, Pennsylvania

NOTICE [redacted] INFORMATION AFFECTING THE [redacted] OF THE UNITED STATES WITHIN THE [redacted] THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS [redacted] 794. ITS TRANSMISSION OR THE REVELATION OF [redacted] IN ANY MANNER TO AN UNAUTHORIZED PER[redacted] PROHIBITED BY LAW.

GRO[redacted] 1
Exclu[redacted] automatic
downgradi[redacted]nd declassification

PREPARED BY:

Experimental Engineering

APPROVED BY:

H. S. McCreary
H. S. McCreary, Manager
Experimental Engineering

W. H. Esselman
W. H. Esselman, Manager
Engineering and Development

NRX-A COMPONENT TEST PROGRAM

X66-50427

(T[redacted])

under NASA-AEC
contract SNP-1

[redacted]

[redacted]L
[redacted]A
[redacted]

TABLE OF CONTENTS

Table of Contents

Table of Contents

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

Table of Contents

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

LIST OF FIGURES

INTRODUCTION

WANL TNR-091 presented a test plan to verify the mechanical design of the NRX-A reactors. The results of this test program combined with the design analysis and the NRX-A1 cold flow test data will be used to establish the suitability of NRX-A2 for power operation and the allowable condition for the test.

The present document, WANL-TNR-095, has taken this test plan and converted it into proposed "Test Specifications". Included are Pert Charts for each major test. In the preparation of these "Test Specifications", it became evident that they must be living documents, in the sense that they are continually undergoing revision as dictated by the changing engineering development situation. It is planned to review these Test Specifications on a continuing basis, and reissue them as they are strengthened in detail. The test specification revisions will be issued singly and will supersede and replace those issued in this document. The test designations established in TNR-091 will be maintained.

Several of the component tests are of a key nature, so that it might be appropriate to discuss their relation to the rest of the program briefly. The flow vibration test (A-11) will be the major tool for studying flow induced vibrations and in deriving stability limitations for the design of full performance seal and lateral support systems.

The full core vibration testing (E-1) occupies a prime role in the program for a number of reasons. First is the proof that the reactor assembly can withstand the vibration and shock levels assumed to be encountered in shipping, ground handling, and actual testing. Second is the study of relative motion of the various parts which may lead to the design of an effectively damped system and will help to decide the placement of instrumentation in the test reactors. Third is the data on fitup and inter-element leakage channels which will be obtained when the vibration test reactor is assembled and variations in fitup observed as it is vibrated and tested; these data are vital to an understanding of pressure relationships within the core. Also, static load and deflection data will be obtained from tests. These tests are preceded by a series of partial height vibration tests (B-5) which yield preliminary data in the above categories, as well as valuable information for the instrumentation and test plan of E-1.

B-3, the seal test, is in fact a series of tests which grade from small tests useful in arriving at the pressure balance for the block I reactors to larger tests which will prove the ability of the seal design to withstand deleterious effects of corrosion and differential expansions on the pressure balances and leakage flows of the seal system. The proper combination of internal heat generation, forces, and hydrogen flow can be only imperfectly simulated outside of the reactor; but a large scale non-nuclear test is the only place in which parameter variations can be studied readily.

Identification of these three as key tests does not mean the others are unimportant. Numerous flow tests are required to size orifices in cases not amenable to precise analysis, and have been underway for some time in support of block I design. The E-2 test is particularly important in studying overall flow imbalances, pointed up in the KIWI-B4-A test, even though the important effects of heat addition are not included in the first model being built.

Mechanical tests have been underway in numerous areas where analysis is difficult and property data questionable. For example, the support block reliability has been improved considerably through design modifications suggested by testing. Data are required on the high temperature strength of fuel elements, and in the behavior of the support system (tie rod, pyro insulation, support block, etc.) under flow conditions in a furnace.

Some general guidelines have been used in the formulation of this program. One of these is that parametric data are appropriate to the present stage of the NRX development effort. This is partly because the environmental conditions of many components are poorly defined, and because environmental conditions and component design will change as the design evolves. Another guideline is that most tests are intended to achieve extremes of a single environment; combined conditions are only studied where the experiments are reasonable or the data are indispensable. Examples of such tests are the corrosion tests (A-2), the hot cluster test (A-10), and the seal test (B-3). The main reason for these tests is that corrosion cannot be studied without combining high temperatures and flowing hydrogen.

[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO. 1

1. TEST NUMBER: A1-1 DATE: 3/30/63

2. TITLE: DYNAMIC MODULUS OF FUEL ELEMENT

3. PURPOSE:

Determine the dynamic modulus of the fuel element for the temperature range of $300^{\circ}R$ to $1500^{\circ}R$ for development grade and production run fuel elements. These values are required by both the design and analytical groups to provide more predictable behavior of these elements.

4. REQUIRED DESIGN DATA:

4.1 Determine the dynamic Young's Modulus in bending.

4.2 Natural frequency of beam response related to the driving force.

4.3 Temperature effects on test specimen elastic modulus.

4.4 Determine the effect of manufacturing dimensional tolerances on the modulus for the different types of fuel elements.

4.5 Determine the relationships of the amount of fuel loading and coating on the modulus.

5. TEST PLAN:

5.1 Description -- The test specimen will be inspected and the weight and dimensions will be accurately determined. The test specimen will be

---

Engineer: Frank A. Sipe

Approved: [signature]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

mounted by two support wires placed at first mode nodal points as shown in Figure 1. The driving force is transmitted to the beam through point A and the resultant forced frequency will be monitored at point B.

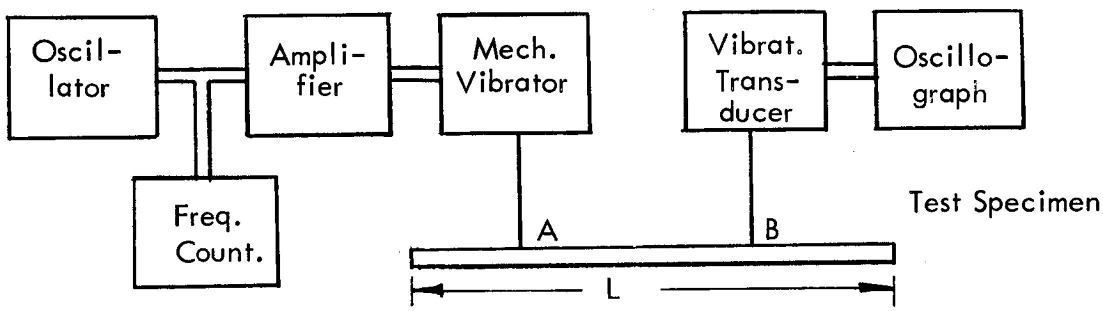


Figure A1.1

5.2 Components Under Test--The fuel element.

5.3 Experimental Set-Up--The test apparatus consists of a (1) electro-mechanical vibrator controlled by an oscillator, driven by a power amplifier, and instrumented with a frequency meter, (2) a recording system consisting of a piezo-electric transducer fed into an oscilloscope and (3) a furnace capable of producing and indicating desired temperatures ranging from 300°R to 1500°R.

5.4 Test Parameters

Electro-Mechanical Vibrator Frequency	0 - 2000 cps.
Vibration Amplitude	0 - max. as displayed on oscilloscope
Length	52" $\pm$ .001"
Weight	2 lbs.
Specimen Temperature	300°R to 1500°R
Fuel Loading	Range of production run elements

5.5 Instrumentation and Data Acquisition--The lengths will be measured to the nearest 0.001" at a controlled temperature. Temperature will be measured with thermocouples. The frequency shall be measured with an electronic frequency counter.

6. ANALYSIS AND DATA UTILIZATION:

6.1 The relationship between the natural frequency and the modulus of elasticity is:

$$f_n = \frac{W_n}{2\pi} = \frac{a}{2\pi}\sqrt{\frac{EIg}{L^3 W}}$$

Where f_n = natural frequency
a = 22.4
g = 386.4 (in/sec^2)
W = weight of specimen (in lbs.)
L = length (in inches)
I = moment of inertia (in.^{4})
E = elastic modulus (in lbs./in^2)

6.2 The values of the modulus of elasticity will be plotted vs. the temperature of the test specimen for each fuel element variable such as fuel loading and surface coating.

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO. 1

1. TEST NUMBER: A 1-2 DATE: 3-30-63

2. TITLE: ELASTIC MODULUS OF FUEL ELEMENT FROM AXIAL BAR TEST

3. PURPOSE:

Determine the dynamic modulus of the fuel element for ambient temperature for development grade and production run fuel elements. These values are required by both the design and analytical groups to better predict behavior of these fuel elements.

4. REQUIRED DESIGN DATA:

4.1 Determine the dynamic Young's Modulus of elasticity.

4.2 Longitudinal natural frequency of the fuel element as a free-free beam.

4.3 Determine the effect of the manufacturing dimensional tolerances on the elastic modulus for the different types of fuel elements.

4.4 Determine the effect of the amount of fuel loading and surface coating on the modulus.

5. TEST PLAN:

5.1 Description - The test specimen used in test A1-I will be mounted by two support wires at first mode nodal points as shown in Figure 1. The driving force will be transmitted to the fuel element through point A and the resultant force and frequency pick-ups will be mounted at point B.

Engineer: Frank A Sipe
Approved: M J Manjoine

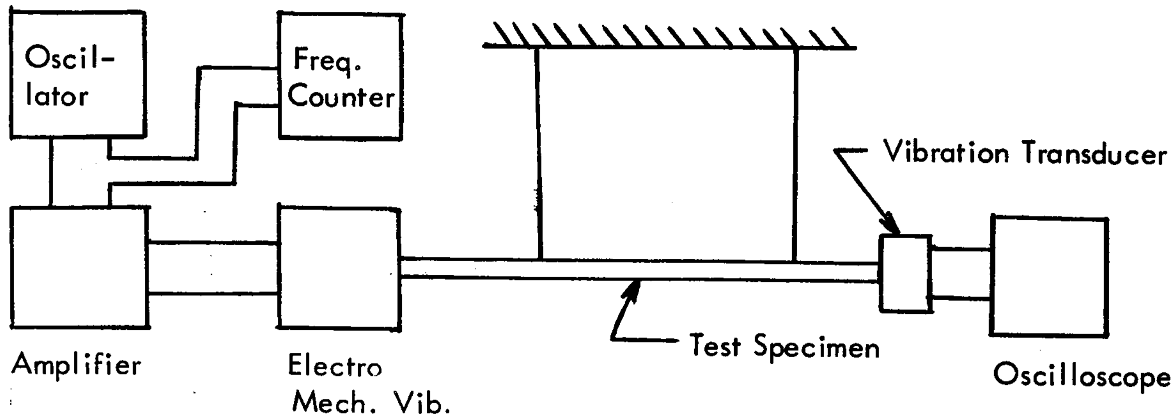


Figure A1•2

The peak amplitudes recorded on the oscilloscope indicate the resonant frequencies.

5.2 Components Under Test - The fuel elements.

5.3 Experimental Set-Up - The test apparatus consists of (1) an electro-mechanical vibrator controlled by an oscillator, driven by a power supply and instrumented with a frequency meter, (2) a piezo-electric transducer fed into an oscilloscope and (3) a furnace capable of producing and indicating designed temperatures ranging from 140°R to 4,000°R.

5.4 Test Parameters

Electro-mechanical Vibrator Frequency	0-2000 cps
Vibration Amplitude	Maximum displayed on oscilloscope
Length	52" ± 0.001"
Weight	2 lb.
Specimen Temperature	Ambient
Fuel Loading	188 mg./cc. - 417 mg./cc.

5.5 Instrumentation and Data Acquisition - The length will be recorded to the nearest 0.001" at a controlled temperature. The frequency shall be measured with an electronic frequency counter.

6. ANALYSIS AND DATA UTILIZATION:

6.1 The relationship between the natural resonant frequency and the modulus of elasticity is:

$$f_n = \frac{W_n}{2} = \frac{1}{2l}\sqrt{\frac{Eg}{W}}$$

where:

f_n = natural resonant frequency

g = 386.4 (in./sec.^{2})

W = weight of specimen (in lbs.).

l = length (in inches)

E = elastic modulus (in lb./in.^{2})

6.2 The values of the modulus of elasticity will be plotted versus the temperature of the test specimen for each fuel element variable, such as fuel loading and surface coating.

Astronuclear

WANL-TNR-095

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION: 1

DATE: 3-30-63

1. TEST NUMBER: A 1-3

2. TEST TITLE: DYNAMIC SHEAR MODULUS OF FUEL ELEMENT

3. PURPOSE:

Determine the dynamic shear modulus of development grade and production run fuel elements at room temperature. These values are required by both the design and analytical groups to insure more predictable behavior.

4. REQUIRED DESIGN DATA:

4.1 Determine the dynamic Shear Modulus.

4.2 Determine the effects of manufacturing dimensional tolerances on the shear modulus for the different types of fuel elements.

4.3 Determine the effect of fuel loading and surface coating on the shear modulus.

5. TEST PLAN:

5.1 Description - Same as test A 1-1 and A 1-2 except that the excitation torque will be the input.

5.2 Component Under Test - The fuel element.

5.3 Experimental Set-Up - Same as A 1-1 and A 1-2.

Engineer: Frank A Sipe

Approved: [illegible]

5.4 Test Parameters

Electro-Mechanical Vibrator Frequency	0 - 2000 cps
Vibration Amplitude	Measured variable
Length	52 in.
Weight	2 lbs.
Specimen Temperature	Room temperature

5.5 Instrumentation and Data Acquisition - Same as test A 1-1 and A 1-2, except that an additional record of a strain gage placed near the end of the test specimen will be made.

6. ANALYSIS AND DATA UTILIZATION:

6.1 The relationship between the torsional natural frequency to the shear modulus is:

$$f_n = \frac{1}{4}\sqrt{\frac{G g A}{W l}}$$

Where:
f_n = natural frequency
g = 386.4 (in./sec.^{2})
W = weight of specimen (lbs.)
A = cross section area (in.^{2})
l = length (in.)
G = shear modulus (lbs./in.^{2})

6.2 Estimate of Poisson's ratio to be calculated from the data from the test A 1-1, A 1-2, and A 1-3, using the following equation:

$$G = \frac{E}{2(1 + \mu)}$$

Where:
E = Young's Modulus
G = Shear Modulus
μ = Poisson's Ratio

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: A 1-4 DATE: 3-30-63

2. TITLE: INTERNAL DAMPING CHARACTERISTICS OF FUEL ELEMENT

3. PURPOSE:

The NERVA engine reactor represents an extremely high energy machine with a very large number of components representing various possible resonant vibrations for a wide range of frequencies. Since a compact design is required for flight application limiting the use of damping devices, the internal damping of the material must be utilized. Data from this test, in conjunction with the friction data on the fuel element allows analytical evaluation of the reactor core design and a prediction of the mechanical performance of the production run and development grade fuel elements.

4. REQUIRED DESIGN DATA:

4.1. Determine the coefficient of damping and/or the damping ratio.

4.2 Determine damping energy per stress cycle.

4.3 Determine blunt areas of vibration.

5. TEST PLAN:

5.1 Description of alternate methods of testing

a) Test specimen will be mounted as a cantilever beam, and plucked at the free end. Resulting amplitude decay will be recorded with respect to time.

Engineer: Frank A Sipe

Approved: [signature]

b) Test specimens will be placed in the tensile test machine, loaded to 200 lbs. pull, and released. The same test will be repeated using 400 lbs. of pull. A continuous record of strain and load will be made.

5.2 Component Under Test - The fuel element

5.3 Experimental Set-Up - The test apparatus consists of a tensile machine, dial gage, strain gage clips for automatic recording of strain, and a vibrator controlled by an oscillator.

5.4 Test Parameters

Frequency	0 — 100 cps.
Amplitude	Measured variable
Length	52 in.
Weight	2 lbs.
Specimen Temperature	Room Temperature
Fuel loading	Production limits

5.5 Instrumentation and Data Acquisition

*a) Strain gage recording near the clamped end and a suitable scale and telescope to record amplitide of oscillation at the free end.

b) Continuous record of load and strain during tensile test.

c) Continuous record of amplitude and frequency.

* a, b, and c correspond to the test descriptions in 5.1.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Logarithmic decrement is given by:

$$\delta = \frac{1}{n} \ln \frac{X_o}{X_n} = \frac{2 \pi \zeta}{\sqrt{1 - \zeta^2}}$$

6.2 Damping energy is determined by computing the area of the hysteris loop.

6.3 The blunt area is computed by:

$$b = \frac{\Delta f}{f_n} \sqrt{\frac{A^2}{A_n^2 - A^2}}$$

where

X_o = initial amplitude

X_n = n th cycle amplitude

ζ = damping factor

A = magnification factor

A_n = magnification factor at resonance

f_n = resonant frequence

Δf = frequency band near f_n for same value of A

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic [redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: A 1-5 — DATE: 3/30/63

2. TITLE: TENSILE AND COMPRESSION STRENGTH OF FUEL ELEMENTS

3. PURPOSE:

Determine the tensile and compression strength of development grade and production run fuel elements, as well as those fuel elements which have undergone the corrosion test described in test specification A 2. Also, determine Poisson's ratio and compare the results with the computed values from the A 1-3 test. These data are required by both design and analysis efforts of the NERVA reactor development.

4. REQUIRED DESIGN DATA:

4.1 Tensile stress-strain curve.

4.2 Compression stress-strain curve.

4.3 Poisson's ratio.

4.4 Hysteresis loop (to be used for A 1-4 tests).

4.5 Effects of manufacturing dimensional tolerance on the tensile and compression strength for the different type of fuel elements.

4.6 Effects of the amount of fuel loading and surface coatings on the tensile and compression strength.

Engineer: Frank A. Sipe

Approved: [illegible]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Ato[redacted]

5. TEST PLAN:

5.1 Description -- The test specimen will be mounted in the tensile test machine, and the force will applied slowly. The force levels and strain will be recorded at 50 lbs. increment.

5.2 Components Under Test

a) The production run and development grade fuel elements.

b) Those fuel elements which have undergone the corrosion tests A 2.

5.3 Experimental Set Up -- The test apparatus consists of tensile test machine with suitable end fittings, strain gage clips, and a suitable dial gage.

5.4 Test Parameters

Load -- 0 to fracture load at 50 lbs. increments.
0 to 400 lbs., then unload

Strain -- Measured variable

Temperature -- Room temperature

5.5 Instrumentation and Data Acquisition -- Load and strain to be recorded at each load level intervals for fracture tests. A continuous record of load and strain to be made for 0 - 400 - 0 lbs. load test.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Plot stress-strain curves for tension and compression.

6.2 Determine Poisson's ratio using the following relationship:

$$_{x} = -\mu \epsilon_{y}$$

Where: ϵ_x = axial strain
ϵ_y = lateral strain
μ = Poisson's ratio

Astronuclear

WANL-TNR-095

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO. 1

DATE: 3/30/63

1. TEST NUMBER: A 1-6
2. TITLE: BENDING TEST OF THE FUEL ELEMENT (Case of Pure Bending)
3. PURPOSE

Determine the fatigue strength of the production run and development grade fuel element for the temperature range from ambient temperature to 5000°R. This allows an analytical evaluation of the design and a prediction of the performance of these parts under the operating conditions.

4. REQUIRED DESIGN DATA:

4.1 Determine stress-strain characteristics of the fuel element.

4.2 Determine the influence of coating thickness on 4.1.

4.3 Determine the influence of fuel loading on 4.1.

4.4 Determine the influence of manufacturing variables on 4.1.

5. TEST PLAN:

5.1 Description -

Specimen will be mounted on the four point load fixture. This loading arrangement will produce a pure bending moment at the mid-span of the specimen. A continuous record of the load and strain will be made. A similar arrangement will be used for elevated temperature tests by enclosing the specimen in a furnace.

5.2 Component Under Test -

The fuel element.

5.3 Experimental Set-up -

The test apparatus includes four point loading fixtures, for both room temperature, and elevated temperature tests,

Engineer: Frank A Sipe

Approved: [illegible]

and a furnace. Heating will be accomplished by passing electric current through the specimen. A coolant loop (water) will be provided to cool the electrodes.

5.4 Test Parameters

Bending Moment	0 to fracture at 20 in. -lb. internal
Strain	Measured Variable
Temperature	Room Temperature to 5000°R

5.5 Instrumentation and Data Acquisition

Load and strain will be recorded at each applied of load level. The deflection of the specimen will be measured by optical methods for the elevated temperature tests. Continuous monitoring of the specimen temperature will be recorded by copper-constantan, chromel-alumel, and tungsten-tungsten rhemium thermocouples.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Plot stress-strain curves for various temperatures.

TEST SPECIFICATION

A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: A 1-7 DATE: 3-30-63

2. TITLE: FATIGUE STRENGTH OF FUEL ELEMENT

3. PURPOSE:

To establish the fatigue strength of production run, development grade, and corrosion tested (A2) fuel elements. These data will allow analytical evaluation of the design and prediction of the performance of fuel elements.

4. REQUIRED DESIGN DATA:

4.1 Fatigue strength as a function of frequency.

4.2 Alternating stress versus steady stress relationship as a function of loading rate.

5. TEST PLAN:

5.1 Description

a) The test specimen will be loaded on the vibration driver as a cantilever beam and the strain is to be measured continuously at the clamped end. Various levels of stress amplitude will be selected, and each test run will be continued until the test specimen is fractured.

b) The test specimen is to be clamped on a suitable fixture as a cantilever beam, then the free end will be attached to a mechanical oscillator. Various steady stress levels are to be set by initial positioning of the

---

Engineer: Frank A. Sipe

Approved: [illegible]

oscillator axis with respect to the specimen center line. The loading rate will be varied by changing the frequency of the vibration.

5.2 Component Under Test - The fuel element.

5.3 Experimental Set-Up - The test apparatus includes a vibrator, mechanical oscillator, and revolution counter.

5.4 Test Parameters

Applied Load	2 lbs. to 100 lbs. (for 6" moment area)
Strain	Measured variable
Temperature	Room temperature
Frequency	0 - 1,000 cps.

5.5 Instrumentation and Data Acquisition - Continuous measurement with a strain gage at the clamped end and at the load will be recorded.
A revolution counter is to be provided with a switch which will be tripped as the specimen fractures.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Plot "stress" versus "number of cycles to fail" curve for various values of frequency (S-N Curve).

6.2 Plot "alternating stress" versus "steady stress" curves for various values of loading rate (Goodman Diagram).

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted] 1954

[redacted]

Astronuclear
WANL-TNR-095

TEST SPECIFICATION
A 1 FUEL ELEMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: A 1-8 DATE: 3/30/63

2. TITLE: FUEL ELEMENT VIBRATION TEST - CLEARANCE STUDY

3. PURPOSE:

Preliminary vibration tests on B-4 fuel elements indicated that failure occurred between 5 and 55 seconds under a 30 cps., 0.3 inch peak to peak, 15 gram excitation with a 1/4 inch clearance gap between the element and the fixture stops that simulated adjacent elements. This test will show the relationship between clearance gap and the fuel element life for various end conditions which simulate NRX-A fuel element tolerance conditions as a function of various excitations.

4. REQUIRED DESIGN DATA:

4.1 The fuel element life as a function of the clearance, excitation amplitude, frequency, and end condition.

4.2 Obtain high speed motion pictures showing the mode of vibration and fracture.

5. TEST PLAN:

5.1 Description--The test specimen is to be mounted in a fixture which provides fixed boundaries. These boundaries are covered with a graphite lining to simulate adjacent elements. Lateral vibratory excitations are to be applied to the fixture to vibrate the test specimen.

5.2 Component Under Test--The fuel element.

5.3 Experimental Set-Up--The test apparatus includes a fixture with suitable end fittings, a vibrator, and a high speed motion picture camera with suitable flood lighting.

Engineer: Frank A. Sipa

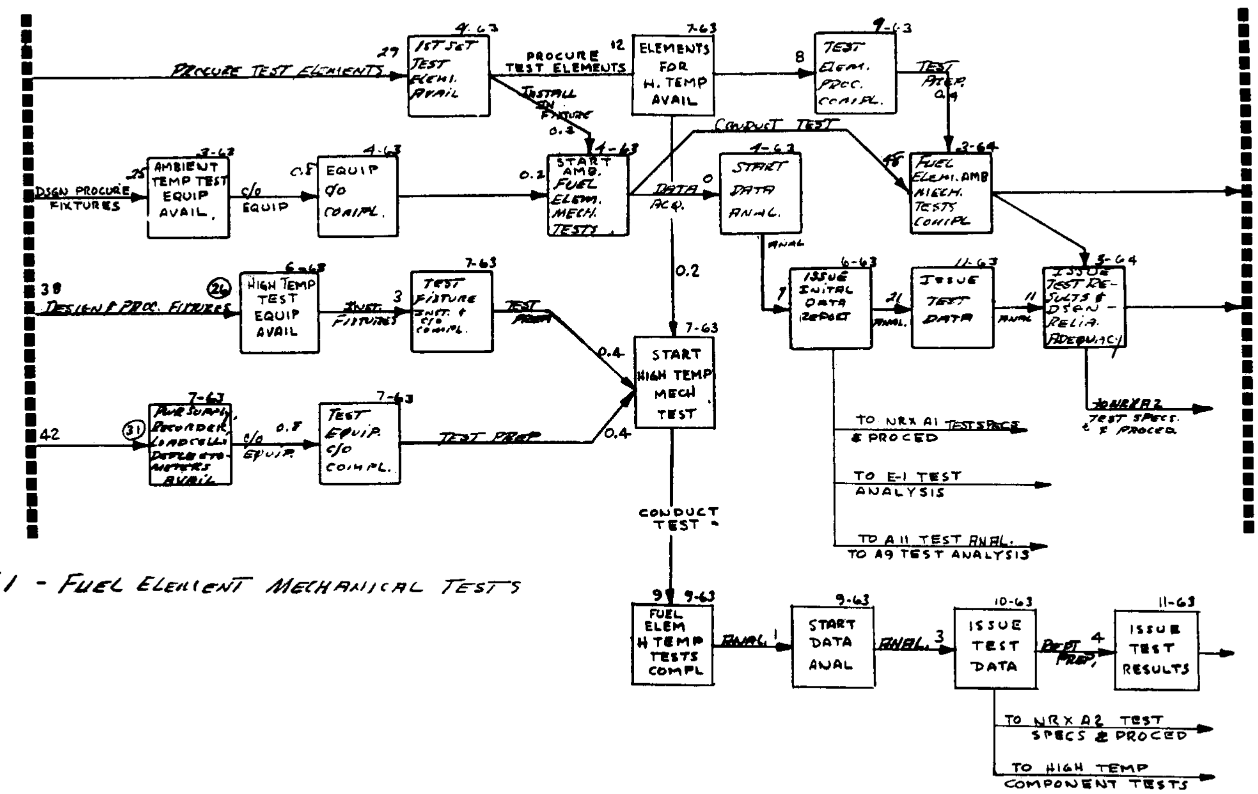
Approved: [illegible]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
A[redacted] 1954

5.4 Test Parameters

End Conditions	Clamp - clamp
	Clamp - free
	Simple - clamp
	Simple - simple
Initial Clearance Between Elements	.010", .050", .100", .200"
Frequency	10 to 500 cps.
Temperature	Ambient
Strain	Measured variable

5.5 Instrumentation and Data Acquisition--Continuous measurement of strains will be made at several positions along the test specimen. Some of the test runs will be photographed with a high speed motion picture camera.



A1 - FUEL ELEMENT MECHANICAL TESTS

A1
4-8-63

TEST SPECIFICATION

A-2 SINGLE ELEMENT CORROSION AND FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 2-1 DATE: 3/30/63

2. TITLE: SINGLE ELEMENT CORROSION TESTS FOR STATISTICAL ANALYSIS

3. PURPOSE:

Corrosion of the core material, if excessive, will seriously jeopardize reactor performance from the standpoint of fuel material loss which leads to neutronic deficiencies as well as attendant disruption of channel heat transfer and flow balance. This test is intended to investigate only the material - loss aspect of the overall element behavior being investigated in subsequent tests. The amount of loss to be expected in each NERVA engine will be determined on a statistical basis by subjecting a percentage of the fuel elements for each reactor to the corrosion test under simulated reactor conditions. The corrosion to be expected in the NRX-A hot test is required to be sure that this reactor is capable of reaching simulated test temperatures and run duration.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine the weight loss and dimensional changes of coated fuel elements under simulated reactor design conditions approximated by resistance heating.

4.2 Determine the effects to the elements of exposure to specified conditions with respect to overall and localized defects in the graphite and/or coating.

Engineer: W. J. Havener

Approved: E. A. De Zubay

4.3 Establish a basis for inspection techniques (non-destructive and destructive) other than gross dimensional changes and weight loss.

4.4 Demonstrate that the element will be within the allowable weight loss limits when exposed to specified pressure, temperature and time conditions.

5. TEST PLAN:

5.1 Description - Fuel elements are mounted in graphite chucks in the center of a horizontal pressure vessel. Gaseous hydrogen flows through the holes in the element and is heated by direct current using the element as the resistance. The element is heated to various temperatures under specified flow, pressure and and time conditions to simulate required reactor conditions (Figure A2-1.1). Post mortem materials examinations will be made.

5.2 Component Under Test - A minimum of one percent of all NERVA fuel elements containing enriched fuel and having the internal flow passage coated with niobium carbide.

5.3 Experimental Set-Up - The element is installed in the center of a water cooled horizontal pressure vessel. The vessel contains nine (9) view ports which permit observation of the element during testing for the purpose of determining element surface temperature. Gaseous hydrogen flows through the holes in the element and an inert helium atmosphere is maintained on the outside of the element. The element is installed in graphite chucks which are in water cooled electrodes which permit direct current flow through the element. A maximum power input of 2.8 MW is available for heating the element. After the hot gas leaves the element, it is discharged into a water cooled heat exchanger for cooling to a temperature compatable with filtering. This is necessary as the corrosion particles contain contaminated material and must not be permitted entrance to the atmosphere. After filtering, the hydrogen is flared and vented to the atmosphere. The pneumatic control system permits varying the flow and pressure conditions of the test and the electrical power controls permit varying the temperature and rate at which power is applied to the element. All major test parameters are recorded so that data can be analyzed as required.

5.4 Test Parameters - (Tentative)

Element Exit Gas Pressure	550 psig
Element Exit Gas Temperature	4270°R
Hydrogen Mass Flow	.050 pps
Time at Temperature	20 minutes

5.5 Instrumentation and Data Acquisition -

5.5.1 Physical dimensions and weights are measured before and after each test by a bow and length gage specially designed for this purpose. Micrometers measures dimensions across the flats. Hole sizes are measured by air flow and taper gages.

5.5.2 Pressures and pressure drops are measured by bellows type instruments and transmitted to pneumatic recorders.

5.5.3 Temperature is measured by thermocouples. Chomel-Alumel thermocouples are used for water temperatures and recorded on strip recorders. Tungsten/tungsten-26 Rhenium thermocouples measure exit gas temperature. This a difficult measurement so that a double sonic orifice placed in series is also used. The theory of operation of this device is that mass flow thru any sonic orifice is proportional to the pressure and area and inversely proportional to the square root of the absolute temperature. If two (2) sonic orifices are placed in series, the mass flow through each must be identical. Hence, if the high pressure is known and the pressure and temperature of the gas is known after a considerable amount of heat has been removed from it, continuity specifies that the pressure ratio squared is proportional to the temperature ratio of the two (2) orifices. Therefore, if the pressures are known, and the lower sonic orifice temperature is known, the higher temperature of the hot sonic orifice can be calculated.

5.5.4 Element surface temperatures are measured by optical pyrometer and measured and recorded by radimatics.

5.5.5 Flow is measured by a calibrated sharp edge orifice and differential pressure cell. The differential pressure is transmitted to a pneumatic recorder with square root extraction.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Dimensional and weight loss changes will be used as the basis for determining that the elements of the particular batch checked meet reactor weight loss and dimensional limitations.

6.2 Flow, pressure drop and temperature data will be used to verify the reactor heat transfer analysis programs.

6.3 Examination by sectioning will permit a determination of the quality of the adherence of the niobium carbide coating to the graphite.

TEST SPECIFICATION

A 2 SINGLE ELEMENT CORROSION AND FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 2-2 DATE: 3/30/63

2. TITLE: SINGLE ELEMENT CORROSION AND FLOW TESTS FOR MATERIAL ANALYSIS

3. PURPOSE:

To achieve production NERVA reactors, the basic parameters effecting corrosion must be understood in order that the elements can be modified as the operating requirements for the reactors are established. The NRX-A hot test has the first corrosion requirements that must be satisfied for successful operation.

4. REQUIRED DESIGN DATA:

4.1 Weight Loss - Determine the effects of temperature, time, pressure and mass flow on the hydrogen corrosion rate of lined elements.

4.2 Thermal Shock - Determine the effect of start-up and shut-down with varying transient times, temperature and rate of power input.

4.3 Determine the effects of known flaws; such as, holes in coating, holes in webbing and blocked holes, on the corrosion behavior of fuel elements.

4.4 Determine whether the types of non-destructive tests available precisely define localized defects which might be caused or exposed by standard statistical corrosion tests.

Engineer: W. J. Havener

Approved: E. A. De Zubay

5. TEST PLAN:

5.1 Description - Fuel elements are mounted in graphite chucks in the center of a horizontal pressure vessel. Gaseous hydrogen flows through the holes in the element and is heated by direct current using the element as the resistance. The pressure, temperature, power and time ramps must be varied to accommodate the mode of operation as required by the predicted operation. The same equipment (shown on Figure A 2-1.1) will be used for this test.

5.2 Components Under Test -

5.2.1 Production NERVA fuel elements.

5.2.2 Fuel elements with various types and thicknesses of coatings.

5.2.3 Fuel elements with known flaws, such as, holes in coating, holes in webbing, blocked holes and cracks.

5.3 Experimental Set-Up - The same basic equipment as described in Test A 2-1, paragraph 5.3 but with minor modifications to install the various elements described in 5.2, above.

5.4 Test Parameters -

Element Exit Gas Pressure	0 - 1000 psig
Element Exit Gas Temperature	500 - 5000°R
Hydrogen Mass Flow	0 - .1 pps
Test Time	Determined by Particular Test

5.5 Instrumentation and Data Acquisition - The same instrumentation as described in Test A 2-1, paragraph 5.5. Special pressure and temperature probes will be developed as required to obtain the data as required in paragraph 4, above.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Dimensional and weight loss changes will be used as a basis for comparative analysis of the various parameters that effect corrosion.

6.2 Thermal shock data will be used in determining the maximum allowable temperature transients without damage to fuel elements.

6.3 The effects of known flaws will be used in determining the changes in heat transfer and friction factor and as a result of these changes, what limits may be placed on reactor operation.

TEST SPECIFICATION

A 2 SINGLE ELEMENT CORROSION AND FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 2-3 DATE: 3/30/63

2. TITLE: SINGLE ELEMENT CORROSION TESTS FOR HEAT TRANSFER ANALYSIS VERIFICATION

3. PURPOSE:

To verify the heat transfer analysis computer program, it is necessary to have test data which duplicates as nearly as possible the NERVA operation conditions, both transient and steady state. The NRX-A heat transfer is based on computer programs that require the verification that this test specification can provide.

4. REQUIRED DESIGN DATA:

4.1 Determine the pressure drop and overall heat transfer coefficients of the production elements, and correlation with corrosion.

4.2 Determine the transient behavior under the influence of thermal shock and permanent or temporary flow maldistributions. This will include the effect of strong temperature gradients.

5. TEST PLAN:

5.1 Description - The heat transfer data will be obtained in the same experimental apparatus and generally follow the same general procedure described

Engineer: W. J. Hovener

Approved: E. A. DeZubay

in A 2-1 and A 2-2. Flow maldistributions will be introduced in the elements by the use of the required orifices. Elements uniformly orificed will be compared with elements orificed unevenly (that is 10 maximum sizes and 9 minimum sizes for the 19 holed fuel elements). Thermal shock will be induced in two ways. The first way will consist of reducing power from the operating valve to zero by opening the power supply breaker under 100% of design hydrogen flow. The second method will evaluate the effect of locally cooling the fuel element on the exterior with a helium jet. The cooling will be monitored with optical temperature measuring instruments.

5.2 Components Under Test - NERVA production fuel elements as described in A 2-2.

5.3 Experimental Set-Up - The same basic equipment as described in Test A 2-1.

5.4 Test Parameters - Same as Test A 2-2.

5.5 Instrumentation and Data Acquisition - Same as Tests A 2-1 and A 2-2.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Pressure drop data will be used to verify the assumptions used in setting up the computer programs.

6.2 A heat balance, that is, electrical heat input minus radiation losses, which can be measured by the absorption of the heat in the water cooled jackets, and by the measurements of the inlet and exhaust temperature, will be used to obtain the heat transfer coefficients.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 2 SINGLE ELEMENT CORROSION AND FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 2-4 DATE: 3/30/63

2. TITLE: POST-MORTEM EXAMINATION OF HYDROGEN CORROSION TEST SAMPLES

3. PURPOSE:

To establish that fuel rod quality, as established by non-destructive testing, is adequate for exposure to a hydrogen atmosphere under specified reference conditions. The acceptable overall weight loss of carbon, uranium, and niobium as determined by reactor analysis must not be exceeded by production elements under these reference conditions. A further objective of this test is to insure that localized attack leading to loss of element integrity does not occur.

4. REQUIRED DESIGN DATA:

1) Detailed dimensional changes resulting from corrosion
2) Local and total composition changes
3) Evidence of eutectic formation and effects
4) Evidence of local defects and progressive corrosion effects.

5. TEST PLAN:

5.1 Description - The corrosion tests will be performed in the experimental apparatus and generally follow the general procedure described in A 2-1 and A 2-2. Prior

Engineer: W J Havener

Approved: E. A. De Zubay

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

to the corrosion test weight and dimensional analysis checks will be made. Following the test the same sequence of measurements will be repeated. The element will then be subjected to eddy current measurements in an attempt to pinpoint local defects which may have developed. It will then be sectioned and examined by standard metallographic means. A minimum of ten (10) transverse sections and six (6) longitudinal sections will be made at equally spaced intervals along the rod. If defects were detected by the eddy current analysis additional sections will be made to study these areas. Measurements will be made on a routine basis of the coating thickness of holes 1, 5, 10, 15, and 19 and a coating thickness profile will be established. Chemical analyses of carbon, uranium, and niobium will be made on material removed from the ten transverse sections to determine a relative material loss profile. Density determinations of the fuel with the niobium carbide liner removed will be made on adjacent material. Attempts will be made to study the radial distribution of uranium by microradiograph or gamma spectrometry of thin transverse sections corresponding to the previous samples. Table I below summarizes the complete test program.

TABLE I. Post-Mortem Hydrogen Corrosion Tests

Parameter	How Determined	Comments
1. Weight change	Pre and post measurements	
2. Dimensional damage	Pre and post measurements	End to end, flat to flat
3. Warpage	Pre and post measurements	
4. Hole Diameter change	Pre and post measurements	End measurements by taper gauge and cold pressure drop measurements for equivalent diameter

TABLE I (Cont)

Parameter	How Determined	Comments
5. Porosity and surface area	Post measurements with Hg porisimeter and gas absorbtion apparatus	Data to be compared to results taken from similar untested rods. These tests will not be made routinely.
6. Metallography a. Coating thickness profile b. Graphite liner interface c. Cracking, pitting, melting, flaking, etc. d. Fuel particle integrity e. Graphite condition	Post-run examination	Data to be compared to untested rods and correlated with NDT.
7. Density determination	Post measurements by wax immersion method and/or Hg porisimetry technique.	Data compared to similar untested rods. NbC liners removed.
8. Chemical analysis of gross longitudinal U, Nb, and C distribution	Post determination by wet chemical techniques	Data compared to process control information and NDT.
9. Radial distribution of U	Gamma ray spectrometry or microradiography	Not a routine test.
10. Room temperature flexural strength	4-point flexure test device	Compared to similar samples. Not a routine test.

A test program using the test plan described above, but simulating corrosion conditions representative of elements operating outside the standard reference conditions (over eutectic temperatures, etc.), will be instituted when sufficient tests have been run at the reference conditions to establish a firm comparison basis. The quality assurance tests will, of course, be on a continuing basis.

5.2 Components under test: NERVA production fuel elements as described in A2-2.

5.3 Experimental setup: The same basic set-up as described in Test A2-1 and other standard laboratory equipment as indicated in 5.1.

5.4 Test parameters: Same as Test A2-2.

5.5 Instrumentation and data acquisitions: Same as Tests A 2-1 and as described under 5.1.

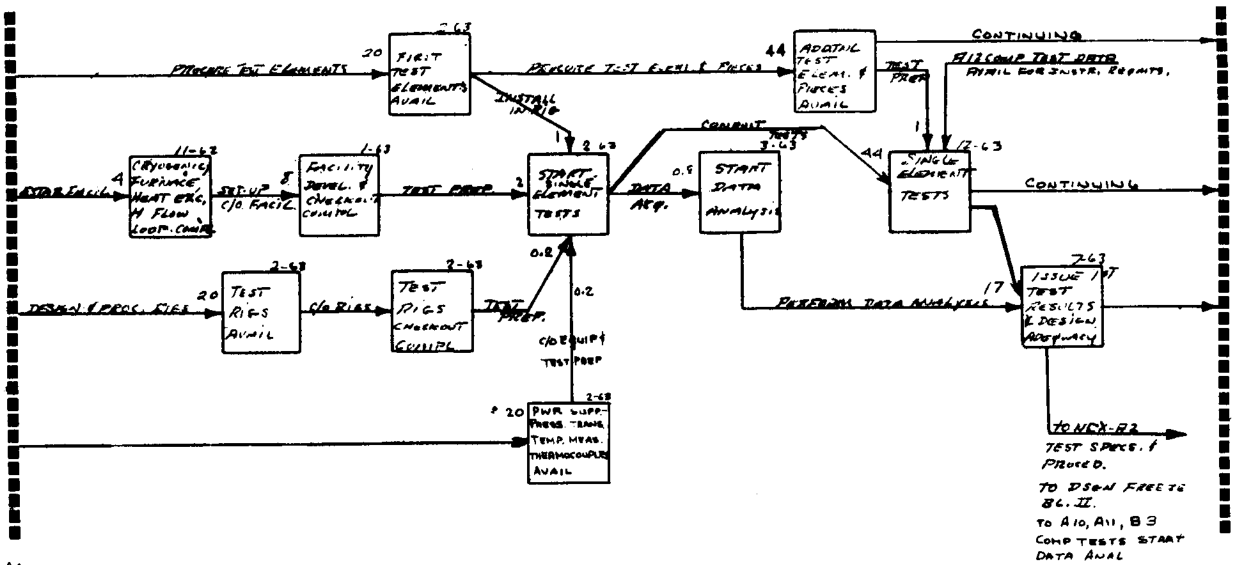
6. ANALYSIS AND DATA UTILIZATION:

6.1 Weight loss data will be used to assure that reactor control and criticality can be maintained during the proposed test.

6.2 The probability of element failure due to local loss of linear integrity will be investigated.

6.3 Segregation of fuel element components resulting from exposure to simulated reactor operation will be evaluated so that the effects on reactor power distributions, temperatures and temperature gradients can be determined.

6.4 Develop recommended operating limits for the existing fuel, and guide development efforts in the fuel program.



A2- Single Element Corrosion & Flow Tests

A2
4-9-63

TEST SPECIFICATION

A 3 UNFUELED HEXAGONAL ELEMENT TEST

REVISION NO: 1

1. TEST NUMBER: A 3 DATE: 3/30/63

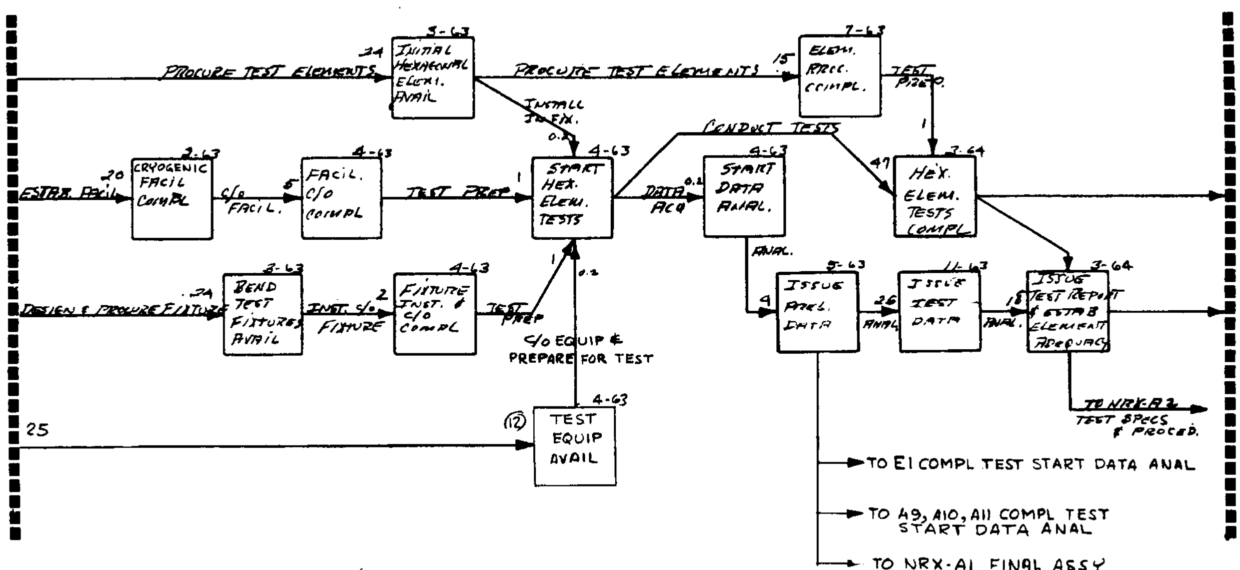
2. TITLE: UNFUELED HEXAGONAL ELEMENT TEST

3. PURPOSE:

This test will obtain the mechanical properties of the Unfueled Hexagonal Element under static and dynamic conditions at room temperature. The detailed purpose and test plan are identical to those given for the tests A 1-1, A 1-2, A 1-3, A 1-4, A 1-5, A 1-6 (excepting the elevated temperature test), and A 1-7. Special attention is to be given to the influence of pyrolytic and stainless steel sleeves, and shim rods on the gross mechanical properties of unfueled hexagonal elements.

Engineer: Frank A. Sipe

Approved: M. J. Manjoine



A3 - UNFUELED HEXAGONAL ELEMENT TESTS

A3
4-8-63

CO[redacted]
R[redacted]
A[redacted]4

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 4 SUPPORT BLOCK FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 4-1 DATE: 3/30/63

2. TITLE: SUPPORT BLOCK TIE ROD INTERACTION FLOW TESTS WITH TRANSPARENT PLEXIGLAS MODEL

3. PURPOSE:

The bottom support block and the tie rod are structural members which retains all the fuel elements in the core. These critical items require extreme optimization in order to insure a successful power run on the NRX-A designs. The tie rod button is partially exposed to mixed exit gas, and the test is designed to assure that the flow patterns which exist in this area adequately cool the button with tie rod channel flow.

4. REQUIRED DESIGN DATA:

4.1 Obtain flow visualization in the tie rod button-support block region.

4.2 Determine the correlation of the tie rod button temperature with respect to immersion distance in the bottom support block with flow rates as parameters.

5. TEST PLAN:

5.1 Description -

5.1.1 Transparent plexiglas models of the support block are used to visualize the flow pattern in the vicinity of the tie rod support. These observations are used to establish the best spatial relation in the support

Engineer: W J Havener

Approved: E. A. De Zubay

~~CONFIDENTIAL~~
[redacted]
~~Atomic Energy Act - 1954~~

system. The apparatus for determining these effects consists of a transparent plexiglas model in which a tie rod, molybdenum cone and a cone support graphite cup are placed. The plexiglas in the vicinity surrounding the support system is drilled with eighteen holes simulating the outer three holes of six fuel elements surrounding the support. Fluids containing various colored dyes are pumped through the tie rod channel and through the element channels and result in flow interactions capable of being visually studied in a qualitative manner.

5.1.2 Warm and cold water also are used to simulate the tie rod channel coolant in the element in order to get quantitative results. With water flow, the temperature difference between the tie rod channel coolant and the tie rod button, as well as the temperature difference between the tie rod channel coolant and the element channel coolant are used to determine the figure of merit of any particular geometry.

5.2 Components Under Test - The test pieces consist of tie rod, molybdenum cone, and plastic pieces simulating the graphite cone supports.

5.3 Experimental Set-Up - The flow model set-up consists of the flow model, a tap water supply and a measuring container to measure the total water flow.

5.4 Test Parameter - Water flow rates and tie rod button position are varied.

5.5 Instrumentation and Data Acquisition - Instrumentation consists of a fluid measuring devices (flowrators), photographic equipment and temperature measuring devices (thermometer and thermocouples).

6. ANALYSIS AND DATA UTILIZATION:

The data obtained from this test indicates the preferred location of the tie rod button. This location will be verified in the hot tests A 4-2.

Astronuclear
WANL-TNR-095

TEST SPECIFICATION
A 4 SUPPORT BLOCK FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 4-2 DATE: 3/30/63

2. TITLE: HOT SUPPORT BLOCK AND TIE ROD FLOW TESTS

3. PURPOSE:

These flow tests will determine the inter-relation of the tie rod support system and the unfueled hexagonal element in order that the structural integrity of this complex system is assured under operating conditions.

4. REQUIRED DESIGN DATA:

4.1 Determine the effect of temperature, pressure, time, and mass flow on the corrosion rate of the unfueled hexagonal element as used with the tie rod, pyro-graphite sleeves, bottom support block and end cone. Measure the flow characteristics of the tie rod channel under high temperature conditions.

4.2 Detect and remedy, if necessary, flow induced vibrations in the tie rod.

4.3 Determine the effect on the components if the tie rod touches the unfueled hexagonal elements.

4.4 Determine the effect of the addition of tantalum carbide-carbon shim rod on the corrosion rate.

4.5 Determine the tie rod button temperature and interaction between the support system and support block.

Engineer: W J Havener

Approved: E. A. De Zubay

5. TEST PLAN:

5.1 Description - The experimental equipment consists of the following: an unfueled hexagonal element complete with tie rod, pyro-graphite sleeves, bottom support block and end cone to be installed in the corrosion furnace described in A 2-1. The heating mechanism has not been fully designed; it will attempt to simulate the thermal gradients in the unfueled hexagonal, pyrolytic graphite sleeve, and stainless steel sleeve of the operating reactor. Provision will be made for eccentric locations of the tie rod within the coolant passage, including a test condition in which the tie rod touches the stainless steel sleeve. Tie rod temperatures will be measured internally.

5.2 Components Under Test - Test pieces consist of fuel elements, center hexagonal element, tie rod, tie rod cone support, bottom support block and end cone.

5.3 Experimental Set-Up - The test system consists of the high temperature corrosion furnace and its associated fluid flow and electrical power systems.

5.4 Test Parameters -

5.4.1	Exit Gas Pressure	0 - 550 psig
5.4.2	Hydrogen Mass Flow Rate	0 - .02 pps (tie rod)
5.4.3	Exit Gas Temperature	500 - 1500°R (tie rod channel)

5.5 Instrumentation and Data Acquisition - The instrumentation as described in Test Specification A 2-1 will be available for standard test run data. In addition, thermocouples will be mounted on the support block and end cone as well as the tie rod. Transducers will be used on the cold end of the element and tie rod to detect vibration.

6. ANALYSIS AND DATA UTILIZATION:

Data evaluation will be used to determine the design adequacy of the tie rods as to the vibrational stability, ability to withstand off center location of wall touching and flow characteristics. The support block and support cone temperature data will be used to determine the adequacy of the components in the support system.

TEST SPECIFICATION

A-4 SUPPORT BLOCK FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 4-3 DATE: 3/30/63

2. TITLE: BOTTOM SUPPORT BLOCK THERMAL GRADIENT TESTS

3. PURPOSE:

The bottom support block is a structural member which maintains all fuel elements in the core during operation. Excessive thermal stress may build-up under asymmetric temperature distributions. This test will determine block integrity with extreme temperature gradients.

4. REQUIRED DESIGN DATA:

4.1 Determine temperature gradients and, if possible, the failure conditions of the complex support block configuration.

4.2 Determine corrosion rates of support block.

5. TEST PLAN:

5.1 Description -

5.1.1 The graphite sector of the bottom support block shown in Figure A 4-3.1 will be used to determine the allowable thermal gradients in the bottom support block. Block will be mounted at the exit of a fuel element which will progressively be heated to higher and higher temperatures.

Engineer: WJ Havener

Approved: E. A. De Zubay

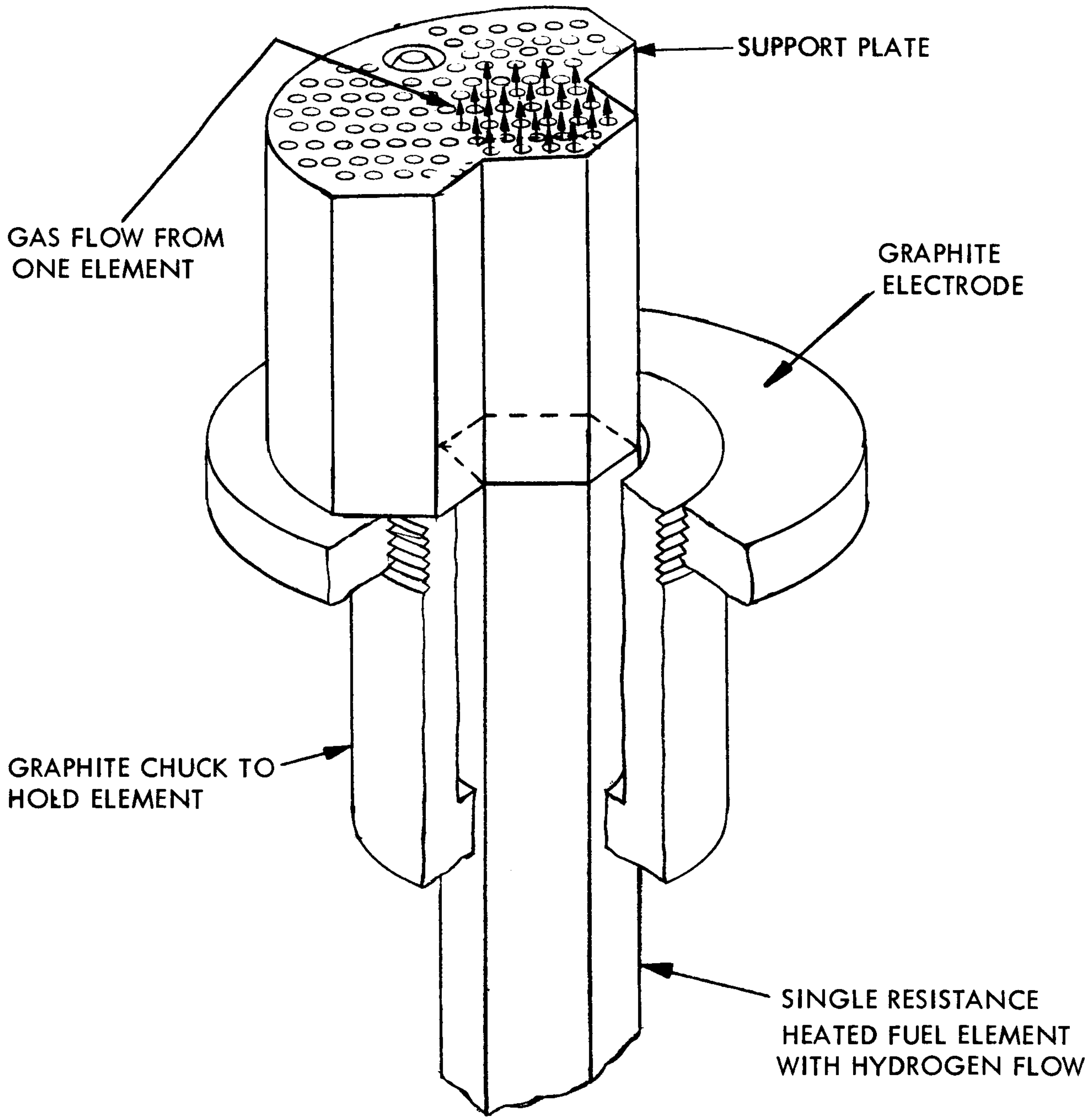


Figure A 4-3.1 Bottom Support Plate Test

The center of the bottom support block will be mounted directly against the electrode. In this manner a definite temperature gradient will be established and can be measured between the outer periphery of the support block and its center where conduction to the furnace electrode will be made. The combined assembly will be placed in the high temperature corrosion furnace and operated through a range of power and flow settings, described in A 2-2.

5.1.2 Corrosion of the support block will also be measured.

5.2 Components Under Test - The required test pieces consist of the support block and associated hardware, and the single fuel element.

5.3 Experimental Set-Up - The test system consists of the high temperature corrosion furnace and its associated fluid flow and electrical power systems. System control is accomplished with the aid of remote control consoles and experimental data is recorded on strip recorders.

5.4 Test Parameters -

5.4.1	Element Exit Gas Pressure	550 psia
5.4.2	Gas Temperature	2000 - 5000°R
5.4.3	Flow Rate of Hydrogen	.01 - .05 pps

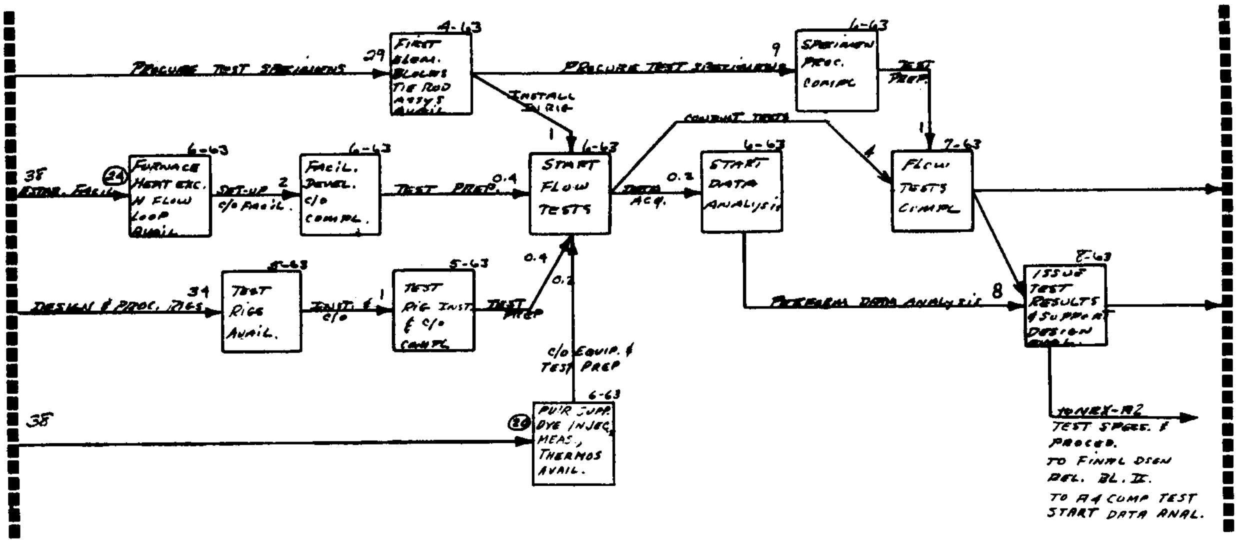
5.5 Instrumentation and Data Acquisition - The overall instrumentation set-up is described in Test Specification A 2-1. All data is recorded on strip recorders. The support block will be instrumented extensively with thermocouples.

6. ANALYSIS AND DATA UTILIZATION:

6.1 These tests will determine whether the support block will function with the expected temperature gradients.

6.2 The maximum temperature gradients which will result in component failure can be determined.

6.3 Corrosion rates of the support block will be determined.



A4 SUPPORT BLOCK FLOW TESTS

A4
4-8-63

~~CONFIDENTIAL~~
~~RESTRICTED~~ DATA
[redacted] Energy Act [redacted]

TEST SPECIFICATION

A 5 SUPPORT BLOCK AND PYROLYTIC PARTS MECHANICAL TEST

REVISION NO. 1

DATE: 3/30/63

1. TEST NUMBER: A 5
2. TITLE: SUPPORT BLOCK AND PYROLYTIC PARTS MECHANICAL TEST
3. PURPOSE:

The purpose of the test is to demonstrate that the support blocks, pyrolytic cups and washers will meet mechanical design requirements.

4. REQUIRED DESIGN DATA:

4.1 Determine the adequacy of the design of pyrolytic parts and support block.

4.2 Determine the effective shear strength of interlocking support blocks.

4.3 Determine the ultimate load sustained by all types of support blocks when subjected to various temperature gradients, alternating axial loads and lateral support loads.

4.4 Attempt to establish the statistical reliability of the fuel cluster support block assembly for static and cyclic loads, and correlate reliability with design calculations.

5. TEST PLAN:

5.1 Description

The test rig will be a canister approximately 2 feet high and 1 foot in diameter. It will be capable of providing cyclic loads to the various shaped support blocks; independent loading to the individual elements mounted on the support blocks; interaction of adjacent support blocks; simulated lateral support loads; and, a large variety of temperature gradients throughout the support blocks. Aerodynamic

Engineer: John J. Schreiber

Approved: [signature]

loads on the cup-core assembly will also be generated.

The test will basically be conducted on one support block assembly at a time. Parameters will be evaluated individually, in various combinations and finally in concert.

5.2 Components Under Test

The various components under investigation will be the molybdenum cone; regular, irregular, coated, uncoated, interlocking and non-interlocking support blocks; pyrolytic graphite cups, washers and sleeves. These will be of production and development designs.

5.3 Experimental Set-up

The experimental set-up will be basically that shown in Figure A 5.3.

5.4 Test Parameters

Test parameters will be individual element loads and molybdenum core loads for both static and dynamic conditions. Temperature distributions throughout the peripheral holes of the support block will be monitored as well as flow rates through the central element.

5.5 Instrumentation and Data Acquisition

Continuous thermocouple read-out from any array of holes in the support block will be provided. Individual load cells on each element and each core will be continuously recorded on a strip chart for both static and dynamic loads on regular and irregular shaped blocks. Initiation of fracture will be detected by acoustic emission from the specimen. Where required, and feasible, strain gages will be used to monitor actual strains in the parts.

6. DATA ANALYSIS:

The test data obtained from the support block tests will be used to:

6.1 Optimize the reliability of the block by evaluating the effect of such design parameters as bearing area, bearing angle, thickness of pyro-washers and length of block.

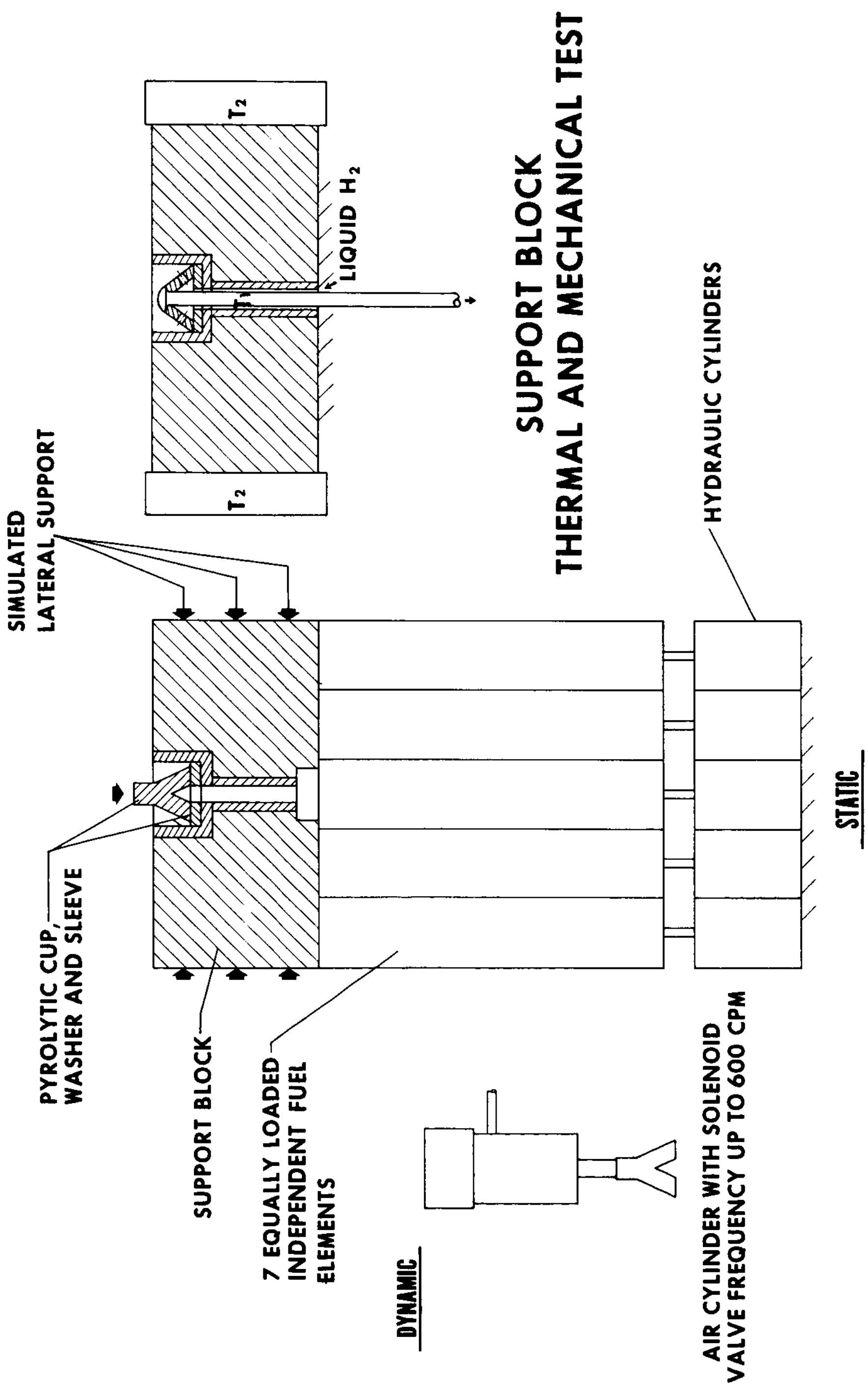


Figure A 5·3 Support Block Test

6.2 Confirm that the correct tie rod sizes are being used by measuring load distribution on irregular support blocks.

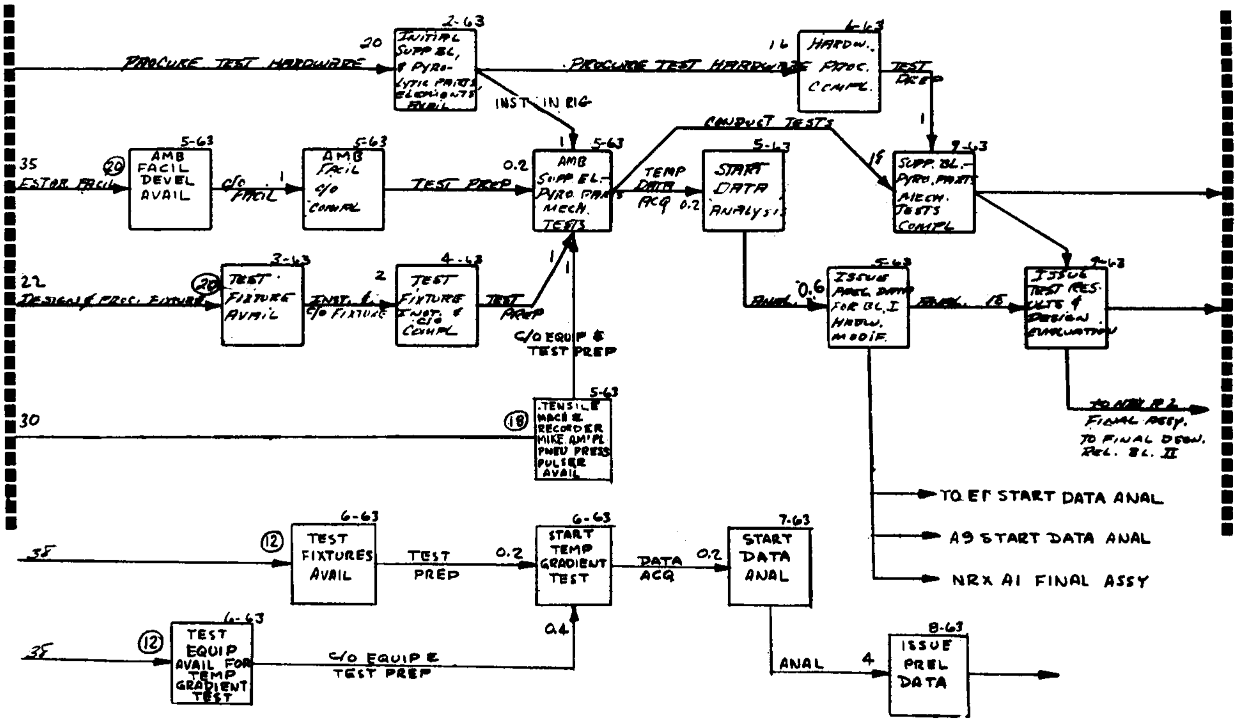
6.3 Attempt to establish the statistical reliability of the fuel cluster support block assembly for static and cyclic loads, and correlate reliability with design calculations.

6.4 Point out areas of redesign to correct conditions of wear on fatigue failure resulting from cyclic loading.

6.5 Determine the effect of coating on block strength and wearability.

6.6 Determine the loads that the interlocking type blocks are capable of supporting when loaded about the periphery.

6.7 Evaluate the effect on reliability of adding an interlock to the support blocks.



A5 [redacted] SUPPORT BLOCK & PYROLYTIC MECHANICAL TEST

A5
4-8-63

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO: 1

1. TEST NUMBER: A 6-1 DATE: 3/30/63

2. TITLE: TIE ROD TEST, ROOM TEMPERATURE STATIC TENSILE

3. PURPOSE:

To determine the ability of the tie rod material and configuration to withstand operating static loads at room temperature.

4. REQUIRED DESIGN DATA:

4.1 Determine the hysteresis loop under preloading of the tie rod.

4.2 Determine the stress-strain to fracture curve of the NRX-A tie rod under static loading.

5. TEST PLAN:

5.1 Description--The tie rod shall be mounted in a tensile test machine loaded to design loads, unloaded and loaded to failure. The stress-strain curve for loading and unloading at design loads, and the curve for stress-strain to fracture loads, shall be recorded.

5.2 Component Under Test--The tie rod.

5.3 Experimental Set-up--The test apparatus consists of a tensile machine with suitable end fittings, strain gage clips for automatically recording strain, and a suitable dial gage for measuring total extension.

Engineer: Griffith Davis

Approved: [illegible]

5.4 Test Parameters

Load - 0 to fracture in 50 lb. increments starting at 500 lbs.

Strain - Measured variable

Temperature - room ambient

5.5 Instrumentation and Data Acquisition

Load shall be read visually on the tensile machine. Strain versus load shall be recorded automatically. Strain to fracture shall be read visually using a dial gage of suitable range.

6. DATA ANALYSIS:

Load and strain values, converted to plots of stress and strain shall be used to obtain:

Allowable preload of tie rods

Maximum loads the tie rods can restrain

Static damping effect of the tie rod

Astronuclear
WANL-TNR-095

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO: 1

1. TEST NUMBER: A 6-2 DATE: 3/30/63

2. TITLE: TIE ROD TEST, LOW TEMPERATURE STATIC TENSILE

3. PURPOSE:

To determine the ability of the tie rod material and configuration to withstand operating static loads at low temperature (140°R).

4. REQUIRED DESIGN DATA:

4.1 Determine the hysteresis loop under preloading of the tie rod.

4.2 Determine the stress-strain to fracture curve of the NRX-A tie rod under static loading.

5. TEST PLAN:

5.1 Description--The tie rod shall be mounted in a tensile test machine and cooled to 140°R. At equilibrium temperature conditions, the tie rod shall be loaded to design loads, unloaded, and loaded to fracture. The stress-strain curve for loading and unloading at design loads, the curve for stress-strain fracture loads, and the temperature history shall be recorded.

5.2 Component Under Test--The tie rod.

Engineer: Griffith Davis

Approved: [illegible]

5.3 Experimental Set-Up--The test apparatus consists of a tensile machine with suitable end fittings, thermocouples, and associated equipment, a container suitable for cooling the tie rod with liquid nitrogen, and a dial gage capable of measuring total extension.

5.4 Test Parameters

Temperature--140°R

Load--in increments of 50 lbs. starting at 500 lbs.

5.5 Instrumentation and Data Acquisition

Load shall be read visually on the tensile machine. Strain shall be read visually using a dial gage of suitable range. Load-deflection curve shall be recorded. Thermocouples shall be monitored throughout the test using a manually adjustable potentiometer.

6. DATA ANALYSIS:

Load and strain values converted to stress and unit strain and plotted, shall be used to obtain:

Allowable preload of the tie rods,

Maximum loads the tie rods can restrain at low temperatures, and

Damping effect of the tie rod.

Astronuclear
WANL-TNR-095

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO: 1

1. TEST NUMBER: A 6-3 DATE: 3/30/63

2. TITLE: TIE ROD TEST, HIGH TEMPERATURE STATIC TENSILE

3. PURPOSE:

To determine the ability of the tie rod material and configuration to withstand operating static loads at high temperatures (to 1800°R).

4. REQUIRED DESIGN DATA:

4.1 Determine the hysteresis loop under preloading of the tie rod.

4.2 Determine the stress-strain to fracture curve of the NRX-A tie rod under static loading.

5. TEST PLAN:

5.1 Description--The tie rod shall be mounted in a tensile test machine and heated to temperatures up to 1800°R, using resistance heating. At equilibrium temperature conditions, the tie rod shall be loaded to design loads, unloaded, and loaded to fracture. The stress-strain curve for loading and unloading at design loads, the curve for stress-strain to fracture loads, and the temperature history, shall be recorded.

5.2 Component Under Test--The tie rod.

Engineer: Griffith Davis
Approved: [signature]

5.3 Experimental Set-Up--The test apparatus consists of a tensile machine with suitable end fittings, thermocouples and associated equipment, an induction reactor to supply adequate current for heating to the required temperatures, and a dial gage capable of measuring total extension.

5.4 Test Parameters

Temperature -- $1360^{\circ}R$, $1800^{\circ}R$

Load -- 0-500 lbs., 0-550 lbs., 0-fracture

Strain -- Measured variable

5.5 Instrumentation and Data Acquisition--Load shall be read visually on the tensile machine. Strain shall be read visually using a dial gage of suitable range. Thermocouples shall be monitored throughout the test using a manually adjustable potentiometer.

6. DATA ANALYSIS:

Load and strain values, converted to stress and unit strain values and plotted, shall be used to obtain:

Allowable preload of the tie rods,

Maximum loads the tie rods can restrain at low temperatures, and

Damping effect of the tie rod.

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO: 1

1. TEST NUMBER: A 6-4 DATE: 3/30/63

2. TITLE: TIE ROD TEST, ROOM TEMPERATURE STATIC AND ALTERNATING LOAD

3. PURPOSE:

To determine the ability of the tie rod material and configuration to withstand operating static and alternating loads at room temperature.

4. REQUIRED DESIGN DATA:

4.1 Determine the fatigue strength of the tie rod under simulated operational static and alternating loads.

5. TEST PLAN:

5.1 Description--The tie rod shall be mounted in a fatigue test machine. The tie rod shall be preloaded with the adjustable spring, then cycled for a suitable period of time at pre-determined alternating loads. Alternating load, cycles, and strain shall be measured throughout the test at suitable intervals.

5.2 Component Under Test--The tie rod.

5.3 Experimental Set-Up--The test apparatus consists of a fatigue test machine with suitable end fittings, strain gages and associated equipment, and a dial gage capable of measuring total extension.

Engineer: Griffith Davis
Approved: [illegible signature]

5.4 Test Parameters

Temperature--Room ambient

Load

Static	500 lbs.	700 lbs.
Alternating	150, 250, 350 lbs.	150, 250, 350, 450, etc. to fracture

Cycles -- 0 - 500,000

Strain -- Measured variable

5.5 Instrumentation and Data Acquisition--Strain shall be measured with both strain gages (using fatigue gages, a bridge network, an amplifier, and an oscilloscope) and a dial gage. Load shall be measured by recording fatigue machine coil current and converted (by means of a conversion chart) to load. Cycles shall be measured by noting time elapsed and cycling frequency (a constant), then converting to total cycles.

6. DATA ANALYSIS:

Load and total strain figure shall be converted to stress-strain data. Fatigue strength can thus be plotted versus cycles to failure, as can fatigue strength versus static strength. In addition, any changes of the modulus of the material with fatigue may be noted.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

Astronuclear
WANL-TNR-095

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO.: 1

1. TEST NUMBER: A 6-5 DATE: 3/30/63

2. TITLE: TIE ROD TEST, HIGH TEMPERATURE STATIC AND ALTERNATING LOAD

3. PURPOSE:

To determine the ability of the tie rod material and configuration to withstand operating static and alternating loads at elevated temperatures (1800^{o}R).

4. REQUIRED DESIGN DATA:

4.1 Determine the fatigue strength of the tie rod at elevated temperatures (to 1800^{o}R) under simulated operational static and alternating loads.

5. TEST PLAN:

5.1 Description--The tie rod shall be mounted in a fatigue test machine. The tie rod shall be preloaded with the adjustable springs, then cycled for a suitable period of time at pre-determined alternating loads. Alternating loads, cycles, temperature and the current required to produce the temperature, and strain shall be measured throughout the test at suitable intervals.

5.2 Component Under Test--The tie rod.

Engineer: Griffith Davis
Approved: [signature]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

5.3 Experimental Set-Up--The test apparatus consists of a fatigue test machine with suitable end fittings, an induction reactor, thermocouples and associated equipment, and a dial gage capable of measuring total extension.

5.4 Test Parameters

Temperature -- 1360°R, 1800°R

Load

Static	500 lbs.	700 lbs.
Alternating	150, 250, 350 lbs., to fracture	150, 250, 350, 450 lbs, to fracture

Cycles -- 0-500,000

Strain -- Measured variable

5.5 Instrumentation and Data Acquisition--Strain shall be measured using a dial gage of suitable range. Load shall be measured by recording the fatigue machine coil current and converting (by means of a conversion chart) to load. Cycles shall be measured by noting elapsed time and cycling frequency (a constant), and converting to total cycles. Temperature shall be measured using a manually adjusted potentiometer.

6. DATA ANALYSIS:

Load and total strain figures converted readily to stress-strain data. Fatigue strength can thus be plotted versus cycles to failure, as can fatigue strength versus static strength and temperature. In addition, any changes of the modulus of the material with fatigue and/or temperature may be noted.

TEST SPECIFICATION
A 6 TIE ROD TEST

REVISION NO: 1

1. TEST NUMBER: A 6-6 DATE: 3-30-63

2. TEST TITLE: TIE ROD TEST, LATERAL VIBRATION

3. PURPOSE:

To determine the ability of the tie rod material and configration to withstand lateral vibratory loads imposed by operating conditions.

4. REQUIRED DESIGN DATA:

4.1 Determine the resonant frequency of the tie rod under combined axial loading and lateral vibratory loads and operational temperatures.

5. TEST PLAN:

5.1 Description - The tie rod shall be mounted in a suitable fixture and vibrated laterally over a range of frequencies, tensile loads, and temperatures. Loads, frequencies, dynamic strain, and temperature shall be measured throughout the test at suitable intervals.

5.2 Component Under Test - The tie rod.

5.3 Experimental Set-Up - The test apparatus consists of an I beam test fixture with required end fittings, a load cell and associated strain gage equipment, an induction reactor, a signal generator, lateral vibrators, thermocouples and associated equipment, and a stroboscopic light.

Engineer: Griffith Davis

Approved: [illegible signature]

5.4 Test Parameters

Temperature - 180°R, Room Temperature, 1360°R, 1800°R

Load - 250 lbs., 500 lbs., 750 lbs.

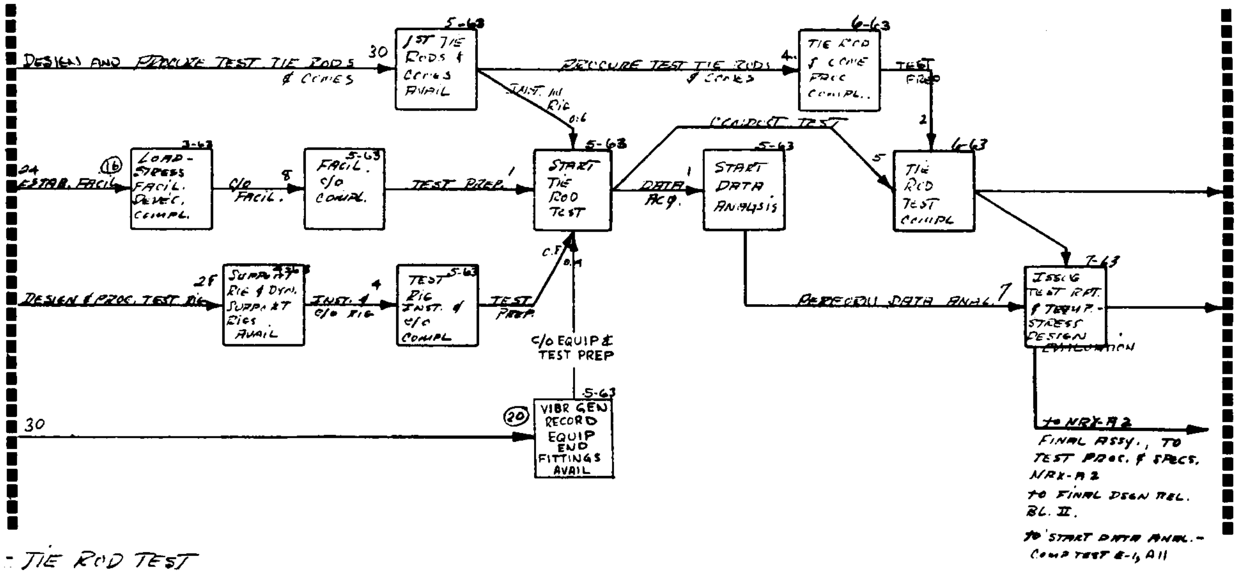
Frequency - 0-20,000 cps.

Dynamic Strain - Measured variable

5.5 Instrumentation and Data Acquisition - Strain shall be measured visually using a stroboscopic light and suitable scale. Load shall be measured with a strain gage load cell. Temperature shall be continually monitored with a manually adjustable potentiometer. Frequency shall be measured directly on an oscilloscope.

6. DATA ANALYSIS:

Resonant frequency and dynamic strain data versus load shall be used to aid in the determination of a suitable preload for the reactor tie rods.



A 6 - TIE ROD TEST

A6
4·8·63

CON[redacted]L
RE[redacted]DATA
At[redacted]1954

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 7 TIE ROD HANGER, BUSHING AND CONE FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 7 DATE: 3/30/63

2. TITLE: TIE ROD HANGER, BUSHING AND CONE FLOW TESTS

3. PURPOSE:

To determine pressure loss coefficients for the tie rod hanger, tie rod centering bushing and tie rod cone support components as a function of the Reynolds Number and configuration of the flow passage in the specific components.

This information is to be used in establishing the size and type of flow passages for the tie rod components to be used in the NERVA reactor, as well as in providing design data for the NRX-A hot test.

4. REQUIRED DESIGN DATA:

4.1 Determine the pressure loss coefficient [redacted] for the following total flow area ranges:

4.1.1	Tie Rod Holder	0.036 - 0.144 in^2
4.1.2	Tie Rod Centering Bushings	0.001 - 0.3 in^2
4.1.3	Tie Rod Cone Supports	0.006 - 0.06 in^2

Engineer: H. J. Fix

Approved: E. A. De Zubay

[redacted]

4.2 Determine the effect of various flow area configurations on the pressure loss coefficients. Included are slots, chamfered and unchamfered circular holes, and any additional configurations which might be suggested for experimental study.

4.3 Study the effect of leakage paths on the pressure loss coefficients. Included are leakage around the tie rod, through the centering bushing seat and through the centering bushing split.

5. TEST PLAN:

5.1 Description - The test fixtures and test pieces are shown in Figures A 7.1 through A 7.7, and the test system is shown in Figure A 7.8. The principle involved is that of measuring the pressure drop through a particular tie rod test piece for a known mass flow rate of gas passing through the test piece. The mass flow rate is determined from the gas pressure and temperature upstream of a calibrated sonic flow orifice. This data, together with the pressures and temperatures read as shown in Figures A 7.5, A 7.6, and A 7.7, is evaluated with Equation (3) to obtain the pressure loss coefficient for the particular test piece mounted in the flow system.

5.2 Components Under Test - The test pieces are shown in a composite view in Figure A 7.1 and the separate pieces are shown with the pertinent test fixture in Figures A 7.2 through A 7.4. In addition to the bushings having chamfered inlets as shown in Figures A 7.1 and A 7.3, additional bushings having unchamfered inlets are to be tested.

5.3 Experimental Set-Up - The overall test system is shown in Figure A 7.8, and the individual test fixtures are shown in Figures A 7.5, A 7.6, and A 7.7. The working fluid is precooled by a counter-flow heat exchanger prior to entering the cooling coil from which it emerges at near liquid nitrogen temperature and enters the test fixture. Appropriate pressure and temperature measurements are taken at the test fixtures. The fixtures are designed to be

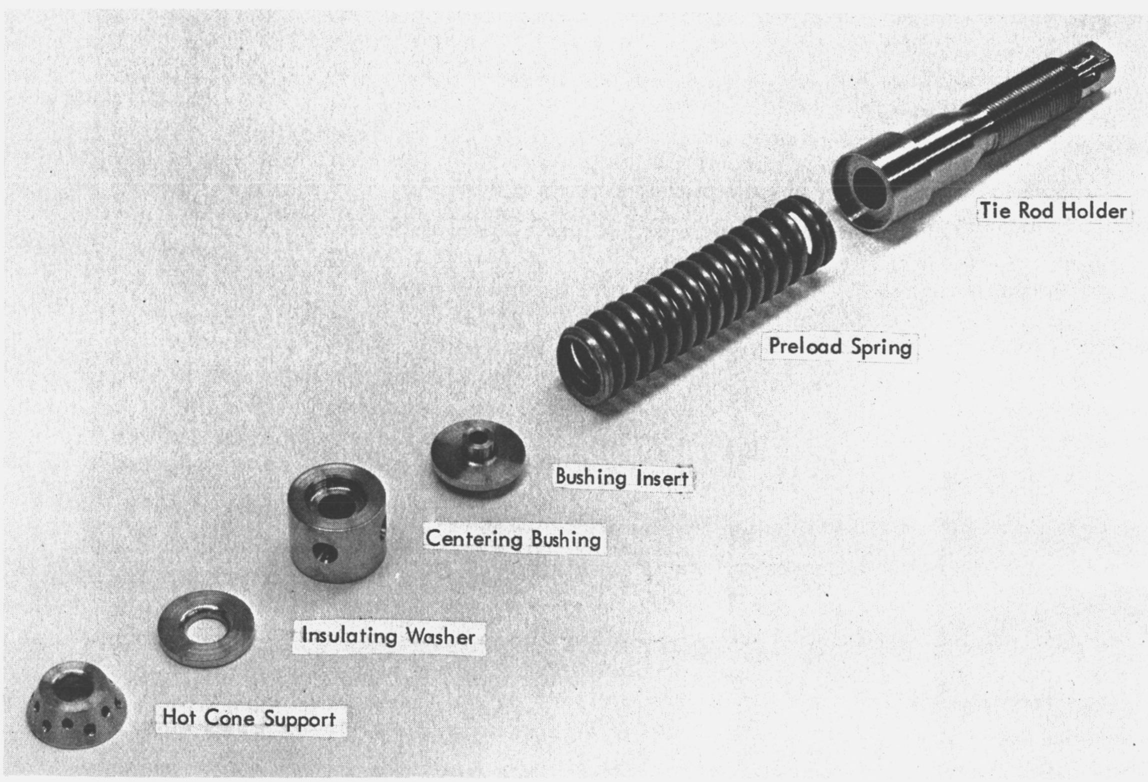


Figure A 7.1 Tie Rod Test Components

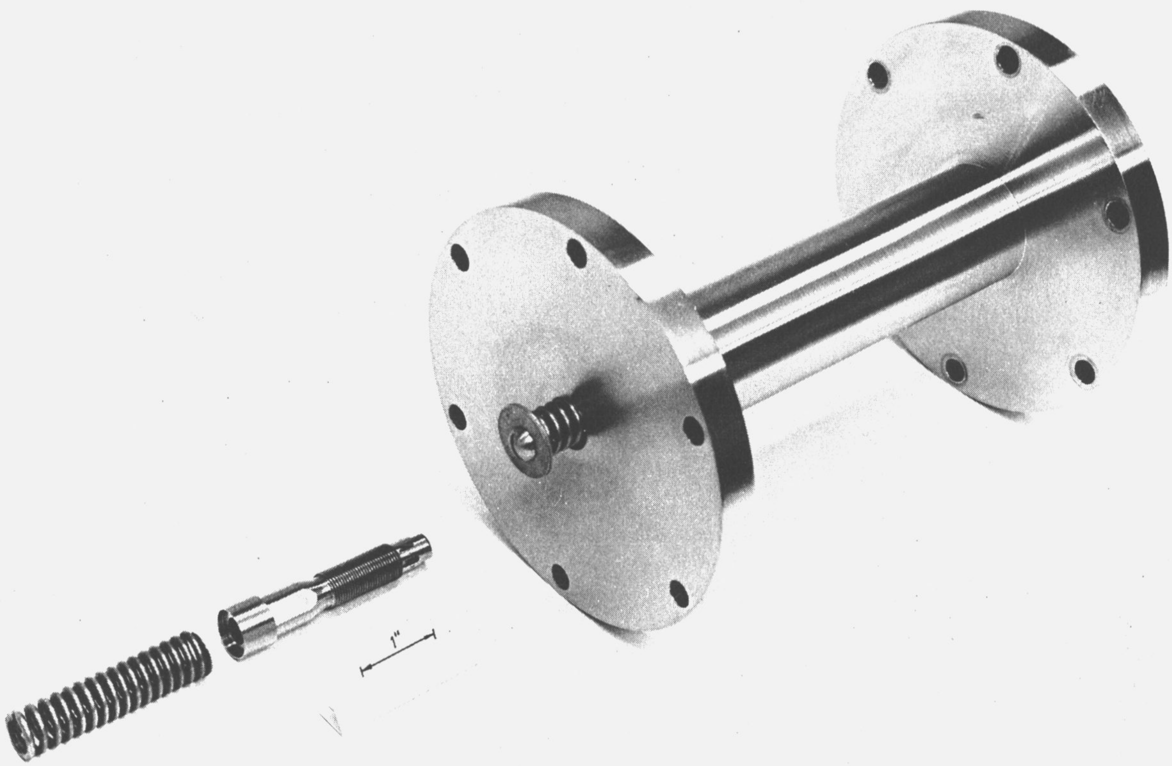


Figure A 7. 2 Tie Rod Holder Test Fixture

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

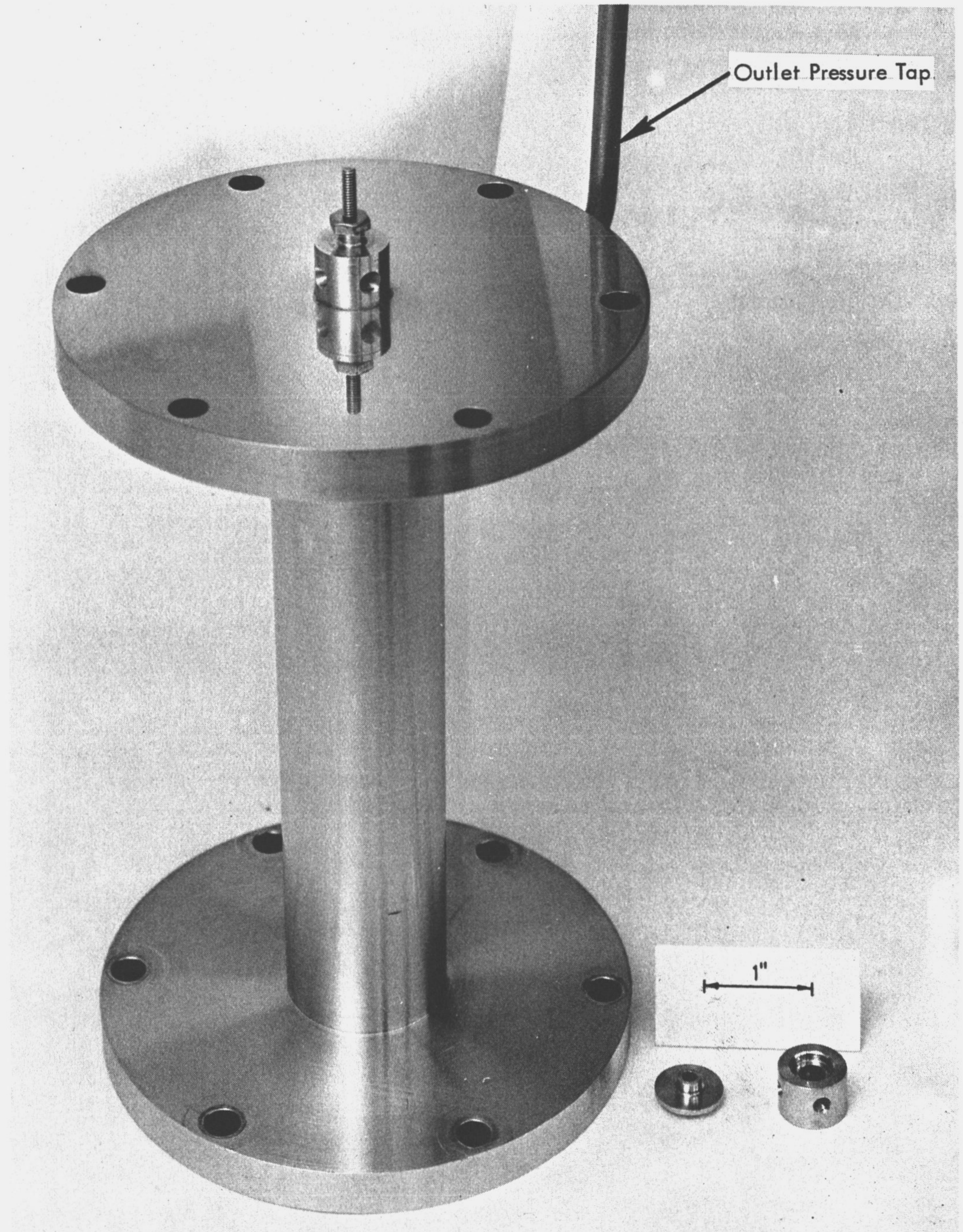


Figure A 7.3 Tie Rod Centering Bushing Test Fixture

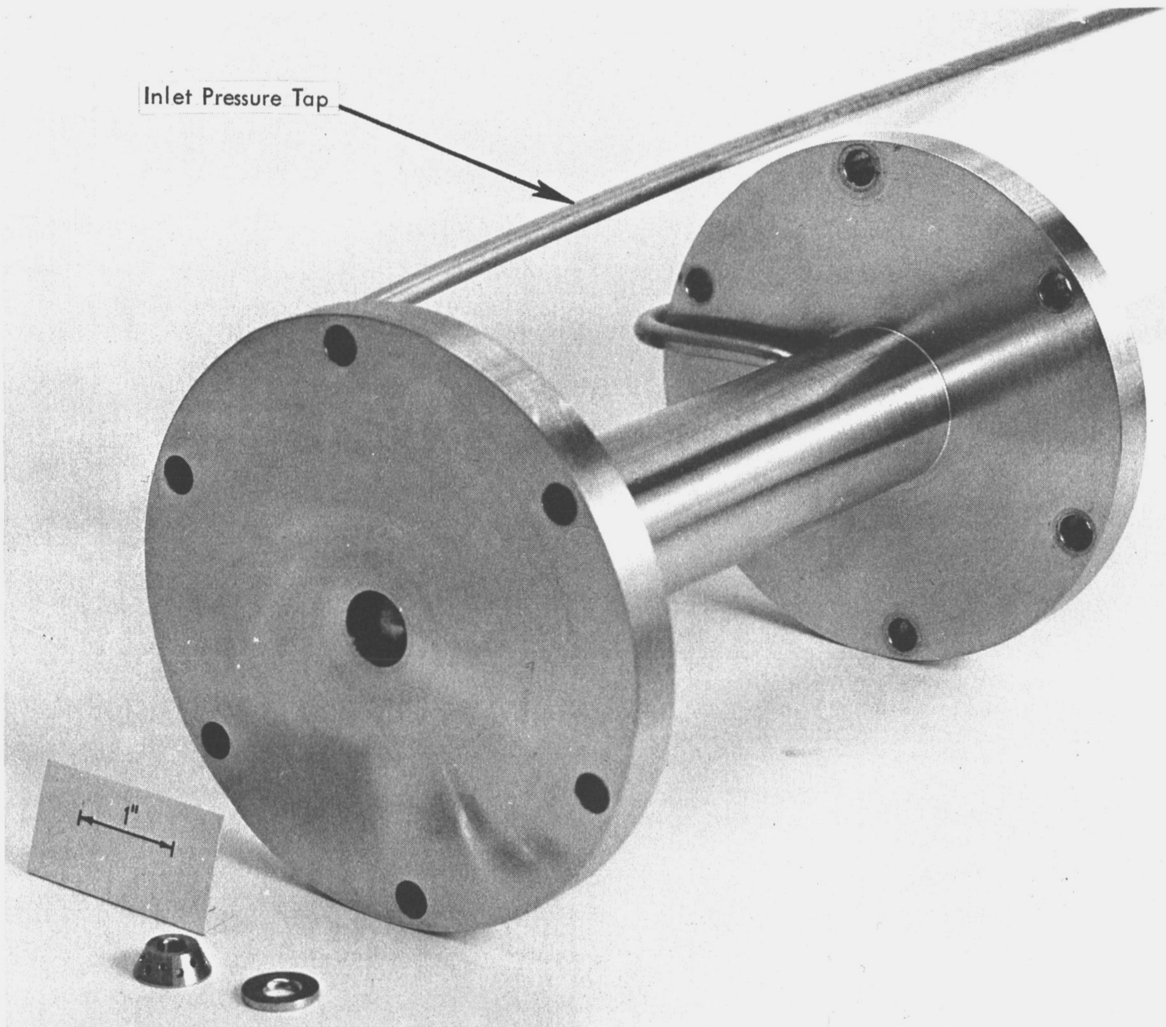


Figure A 7.4 Tie Rod Cone Support Test Fixture

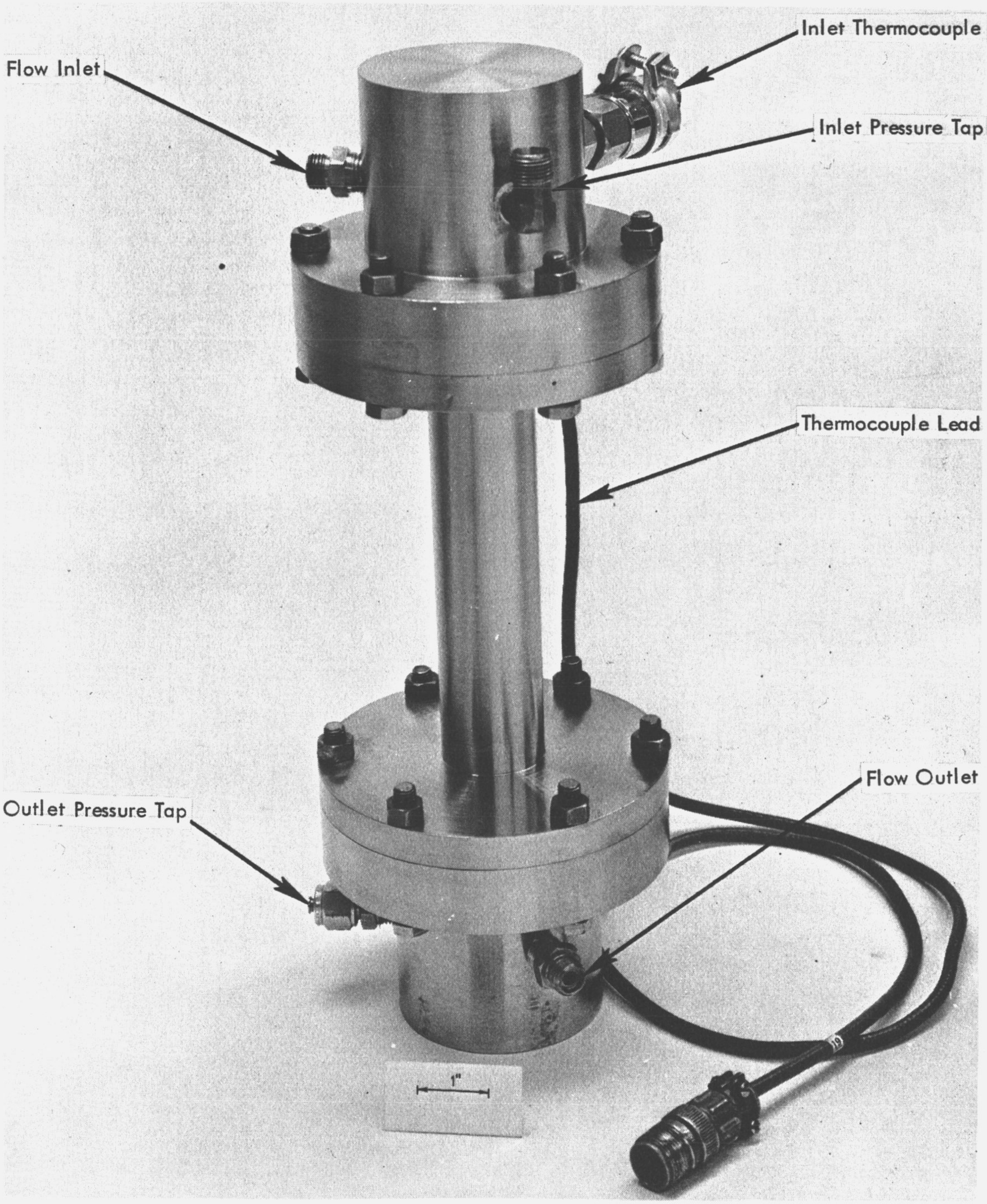


Figure A 7.5 Tie Rod Holder Test Assembly

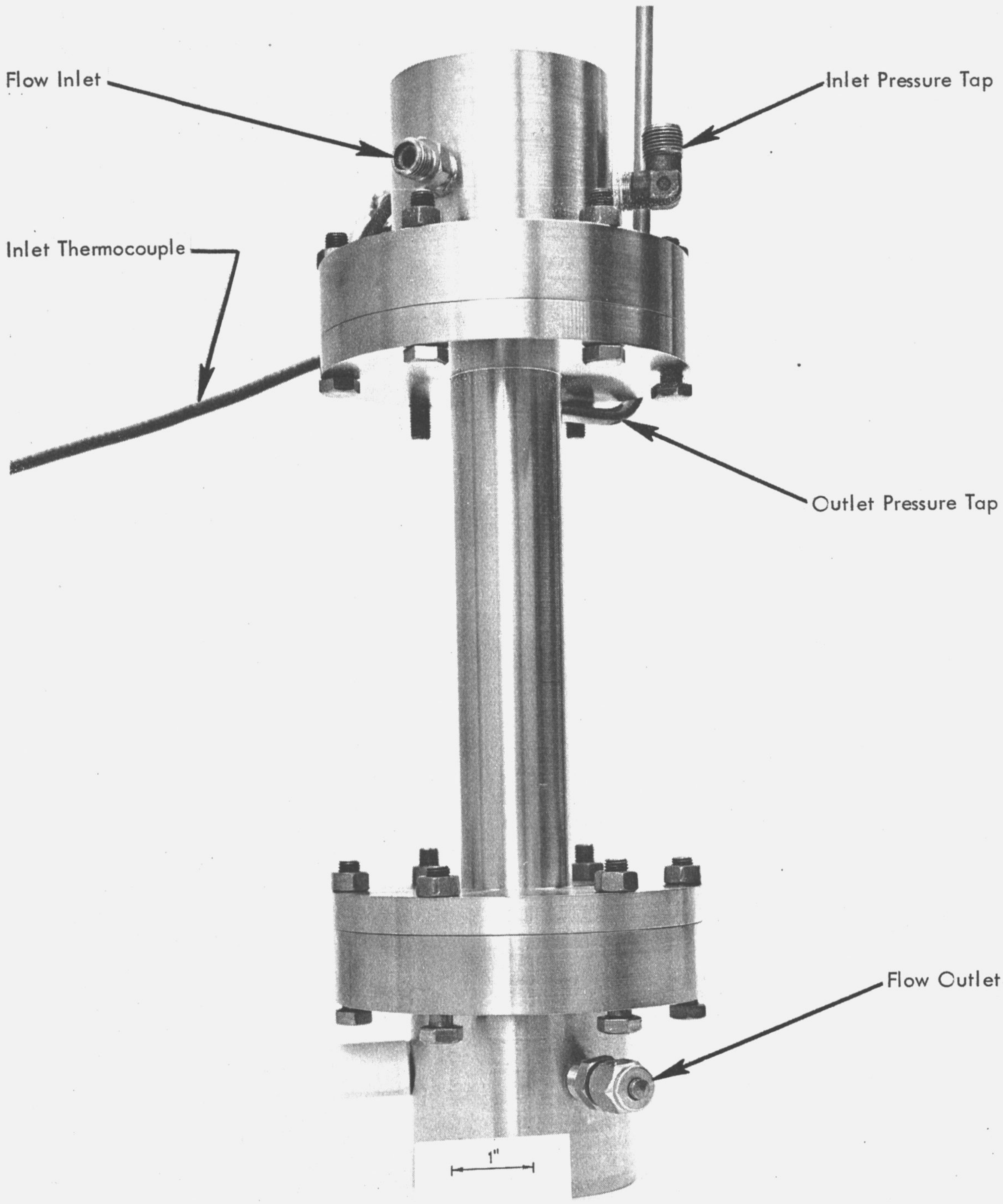


Figure A 7.6 Tie Rod Centering Bushing Test Assembly

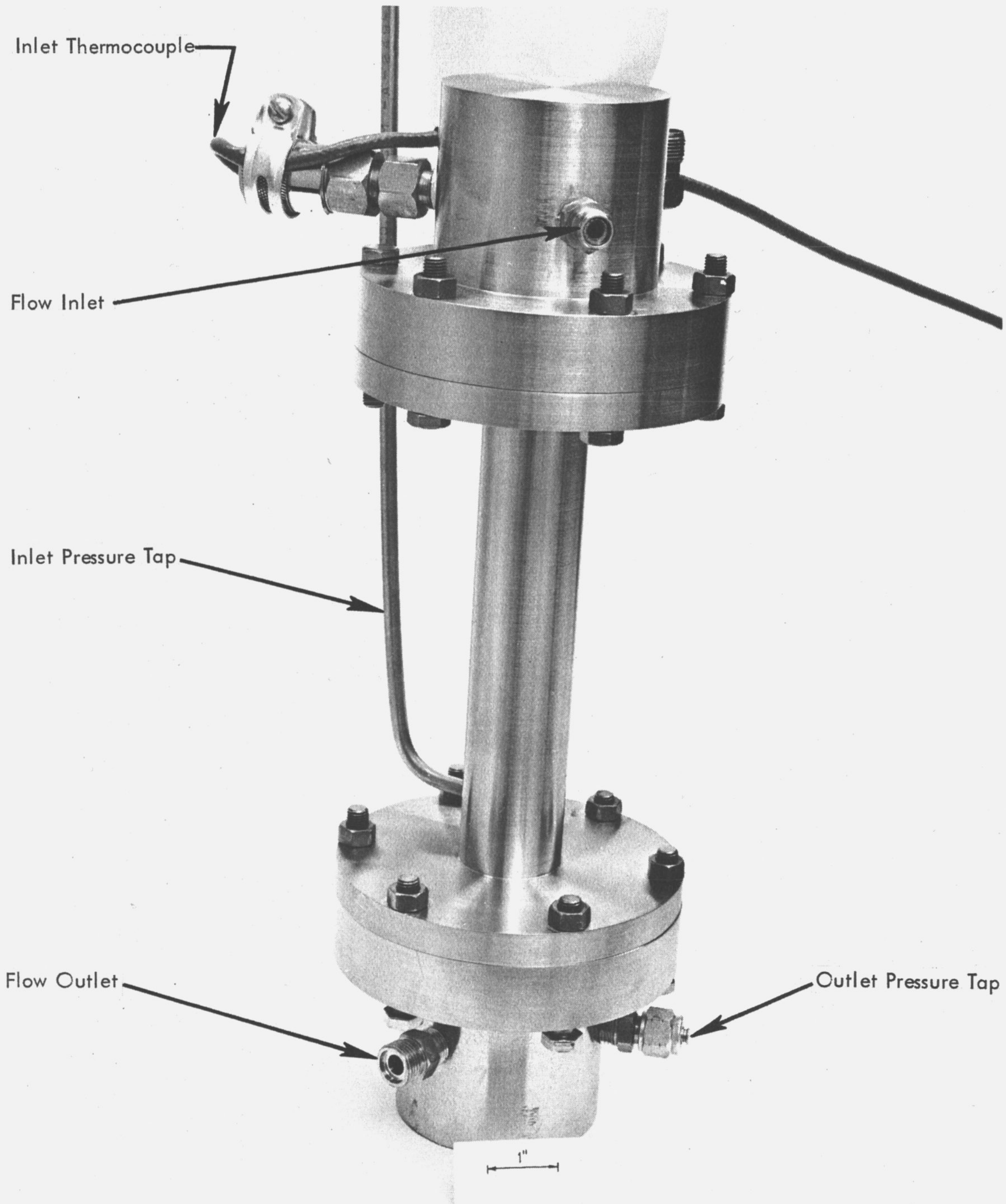


Figure A 7.7 Tie Rod Cone Support Test Assembly

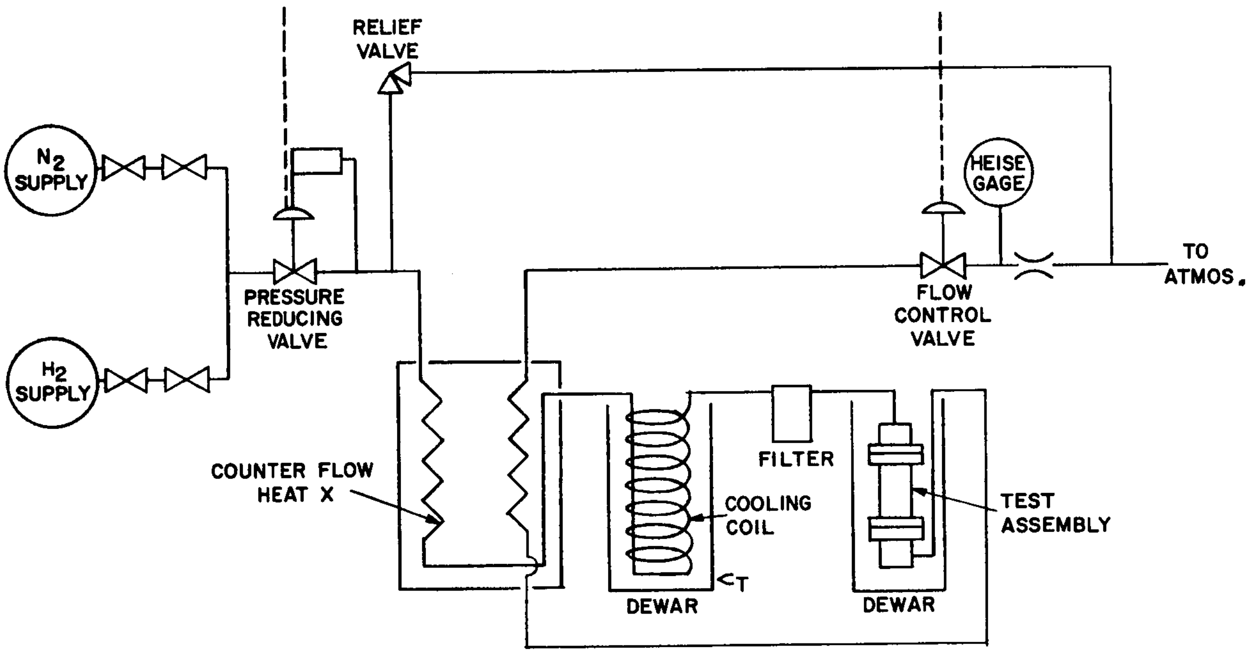


Figure A 7.8 Basic Flow System

completely submerged in liquid nitrogen to provide for isothermal test conditions. The test pieces and test fixtures are designed to duplicate flow conditions in the actual reactor. The mass flow rate of the working fluid is measured by a calibrated sonic flow orifice.

5.4 Test Parameters -

5.4.1	Inlet Pressure	570 - 675 psia
5.4.2	Inlet Temperature	100 - 600°R
5.4.3	Mass Flow Rate	10 - 50 lb/hr.
5.4.4	Total Flow Area	
	Holder	0.036 - 0.144 in^2
	Centering Bushing	0.001 - 0.3 in^2
	Cone Support	0.006 - 0.06 in^2
5.4.5	Pressure Drop	(Measured Variable)

5.5 Instrumentation and Data Acquisition - All pressures and pressure differentials are read visually. Pressures are read from direct reading gauges, pressure differentials are read from mercury manometers, and temperatures are determined from multi-channel potentiometers. Flow measurements are obtained from pressures and temperatures read at a sonic flow orifice which was calibrated against a wet test meter.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Analysis - The pressure drop coefficient as used herein is defined as:

$$C = \frac{2g(\Delta P)}{\rho V^2}$$

where

C = pressure drop coefficient (dimensionless)

g = gravitational constant (ft/sec^2)

ΔP = static pressure drop across the component (lbs/ft^2)

ρ = density of the working fluid (lbs/ft^3)

V = velocity of hydrogen in the component flow restriction (ft/sec)

The mass flow rate, lbs/hr, of the working fluid is measured by a calibrated sonic orifice flow meter and is given as:

$$M = K\, P_f/(T_f)^{1/2}$$

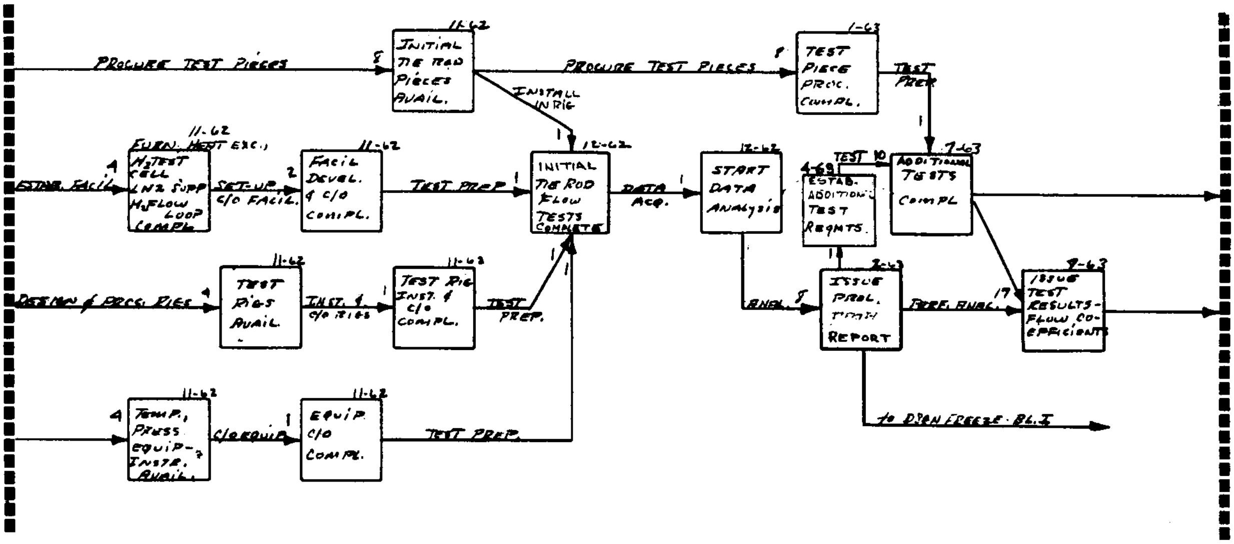
where
M = mass flow rate (lbs/hr)
K = flow constant (lbs-$(^{\circ}R)^{1/2}$/psi-hr)
P_f = flow meter pressure (psia)
T_f = flow meter temperature ($^{\circ}$R)

These two relations are combined and all quantities expressed in the units obtained from actual tests. The resulting expression gives the pressure loss coefficient for any component as:

$$C = \frac{8.3\,(10)^8\, A^2\, (\Delta P)}{R\, K^2} \; \frac{P_1}{(P_f)^2} \; \frac{T_f}{T_1}$$

where
A = component flow area (in^2)
R = gas constant (ft/$^{\circ}$R)
ΔP = component pressure drop (lbs/in^2)
P_1 = component inlet pressure (psia)
P_f = flow meter pressure (psia)
T_f = flow meter temperature ($^{\circ}$R)
T_1 = component inlet temperature ($^{\circ}$R)

6.2 Data Utilization - The pressure loss coefficients obtained from these tests will be utilized in establishing design criteria for tie rod component pressure drop requirements as a function of component flow area magnitude and configuration.



A7 - TIE ROD HANGER, BUSHING & CONE FLOW TESTS

A7
4-8-63

CONF[redacted]
RES[redacted]A
Ato[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 8 FUEL ELEMENT ORIFICE FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: A 8 DATE: 3/30/63

2. TITLE: FUEL ELEMENT ORIFICE FLOW TEST

3. PURPOSE:

Orifices are required to balance the heat transfer to the propellant with the power distribution in the core to insure a uniform core outlet gas temperature. Measurements of flow impedances (pressure coefficients) are necessary in order to predict flow behavior of individual flow paths.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine the orifice coefficient (ϕ) for 12 diameter sizes ranging from 0.0225 inches to 0.070 inches, over the operating envelope.

4.2 Determine the effect of manufacturing tolerances on the orifice coefficients for a particular size of orifice and identify those which can be used as masters.

4.3 Establish the degree of leakage which can reasonably be expected and its effect on orifice coefficients, initially under specified test conditions and under elevated orifice temperatures comparable to reactor operating temperatures.

4.4 Establish the methods that can be used for high speed testing of production orifices.

Engineer: H. J. Fix

Approved: E. A. De Zubay

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

4.5 Test the integrity of the color identification for coding the orifice sizes.

4.6 Determine the effect of cross flow upon orifice loss coefficient.

4.7 Determine the effect of manufacturing tolerances and assembly procedures, i.e., cluster plate proximity and alignment, flow hole eccentricity, channel diameter, on the loss coefficient.

5. TEST PLAN:

5.1 Description -

5.1.1 The orifice is mounted in a flow passage such that the mass flow through it and the pressure drop can be measured accurately. The orifices are measured optically and this information is used to calculate the pressure coefficient. Alterations will be made to the basic test fixture in order to investigate the effect of cross flow, cluster plate proximity and alignment, flow hole eccentricity and channel diameter.

5.1.2 For leakage determinations, the orifice is mounted in a channel which is connected to an inlet and outlet plenum. The leakage flow through the seal is measured for various degrees of leakage, i.e., no adhesive, various amounts and types of adhesives.

5.1.3 If coloring of the orifices for size identification is used, the samples to be tested will be mounted in a hydrogen atmosphere at design pressures and temperatures for various periods of time. The effect of the environment on the integrity of the color coding will be determined.

5.2 Components Under Test - The orifice shown on Figure A 8-1 is the component under test. Blank orifices will also be used to determine the seal leakage.

5.3 Experimental Set-Up -

5.3.1 The test apparatus for flow testing consists of the gas supply, suitable reducing valves, counter flow heat exchanger for cooling the gas, filters, the test assembly, the flow control valve and the sonic measuring

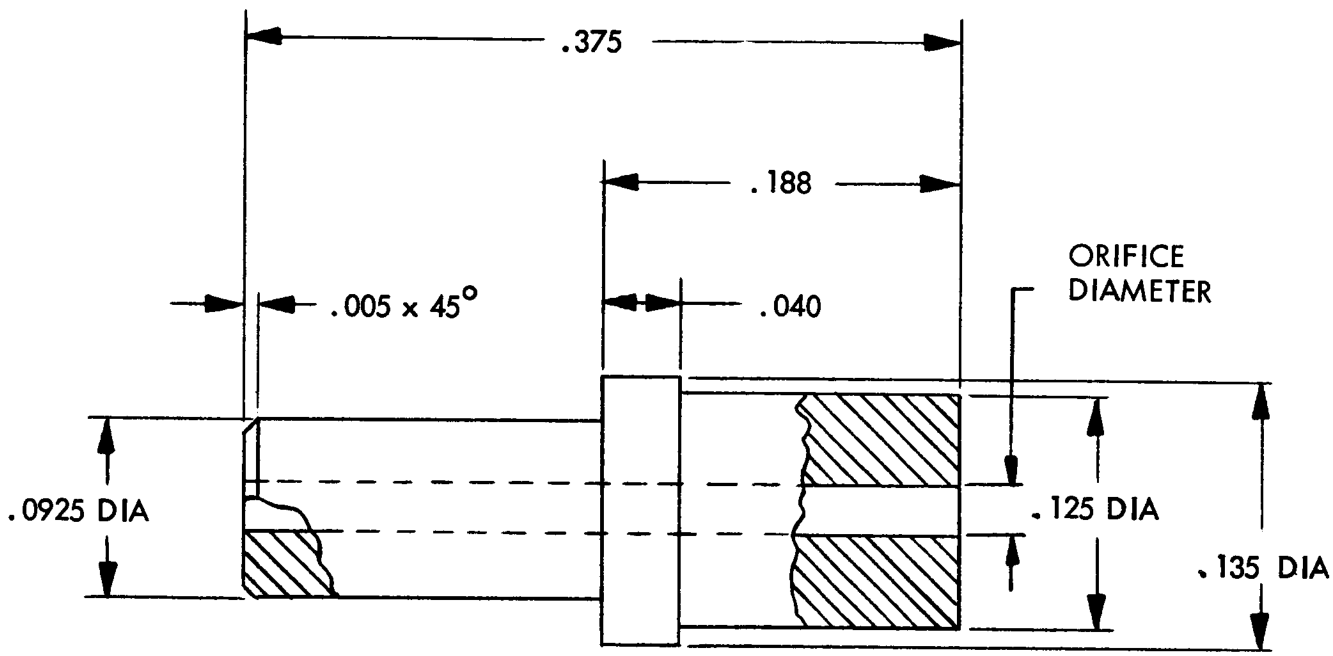


Figure A 8.1 Fuel Element Orifice

orifice (Figure A 8-2). The precision calibration flow passage consists of a plenum chamber. The orifice being tested (shown in Figure A 8-3) seats in a simulated orifice plate and extends into a tube approximately the same diameter as the hole in the fuel element. The length of the simulating fuel element hole is 26 inches. A pressure tap is located two (2) inches downstream from the orifice. The exit of the tube again goes into a plenum chamber where pressure measurements can be made. The entire flow passage is so designed that it can be immersed completely in liquid nitrogen such that isothermal conditions of operation can regularly be attained.

5.3.2 The test apparatus for leakage determination consists of the gas supply and a pressure regulator. A blank orifice to be seal tested is mounted in a rig consisting of an inlet plenum, a simulated fuel element and an outlet plenum. Pressure is measured in both plenums and the leakage flow through the orifice determined.

5.3.3 The test apparatus for testing the integrity of the color coding consists of a hydrogen gas supply, a pressure regulator and an environmental chamber. Temperature within the environmental chamber is controlled. Integrity of the color coding is determined by visual inspection.

5.4 Test Parameters -

Inlet Pressure	320 - 675 psig
Inlet Temperature	140 - 530^{O}R
Mass Flow	.0003 - 0.003 pps
Orifice Diameter	0.020 - 0.070 inches
Pressure Drop	(Measured Variable)

5.5 Instrumentation and Data Acquisition - These tests are made under equilibrated conditions. Pressures and pressure drops are read visually. Precision Heise gages are used for measurement. Copper constantan thermocouples are used to

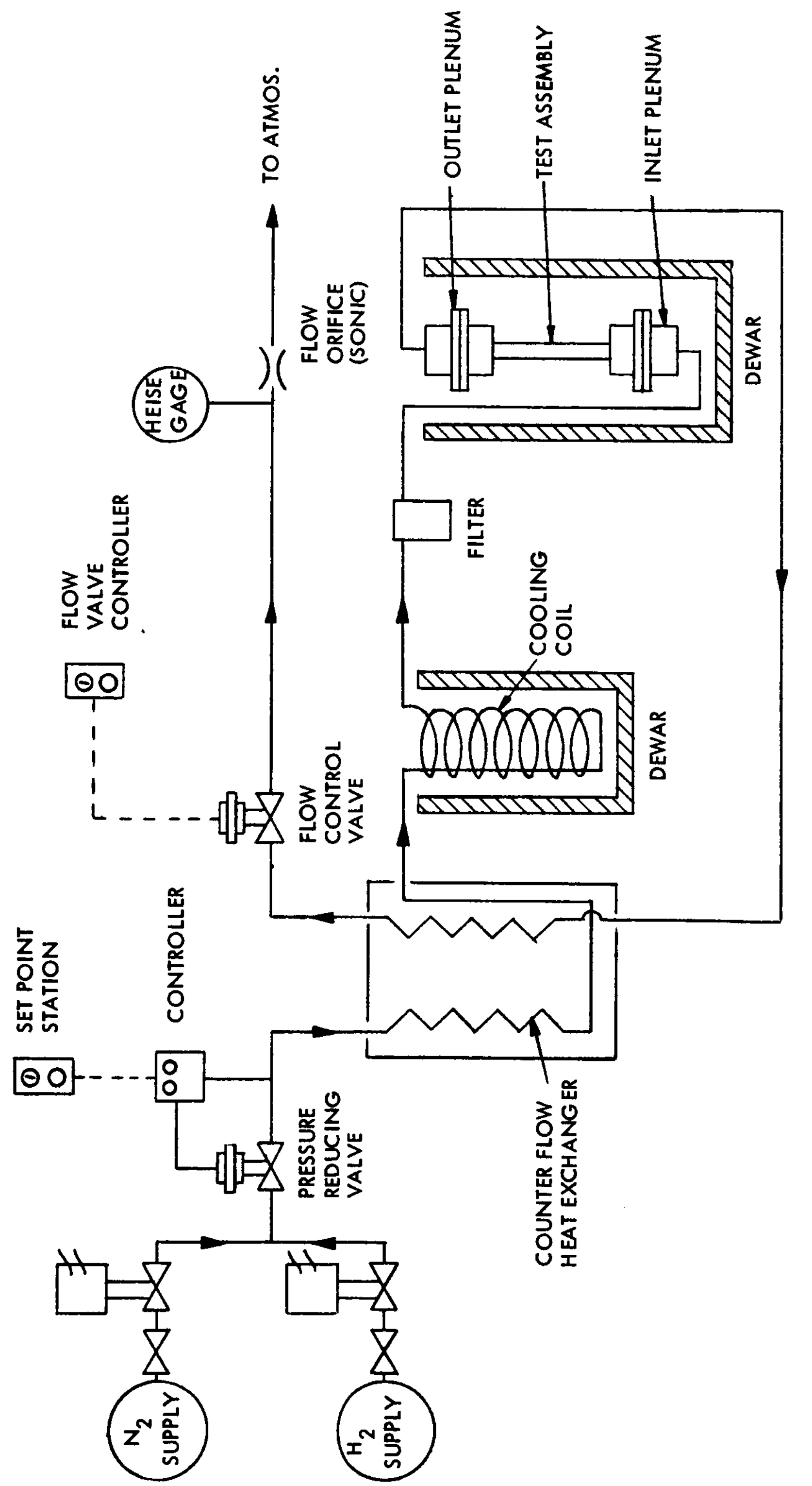


Figure A 8.2 Small Scale Basic Flow System

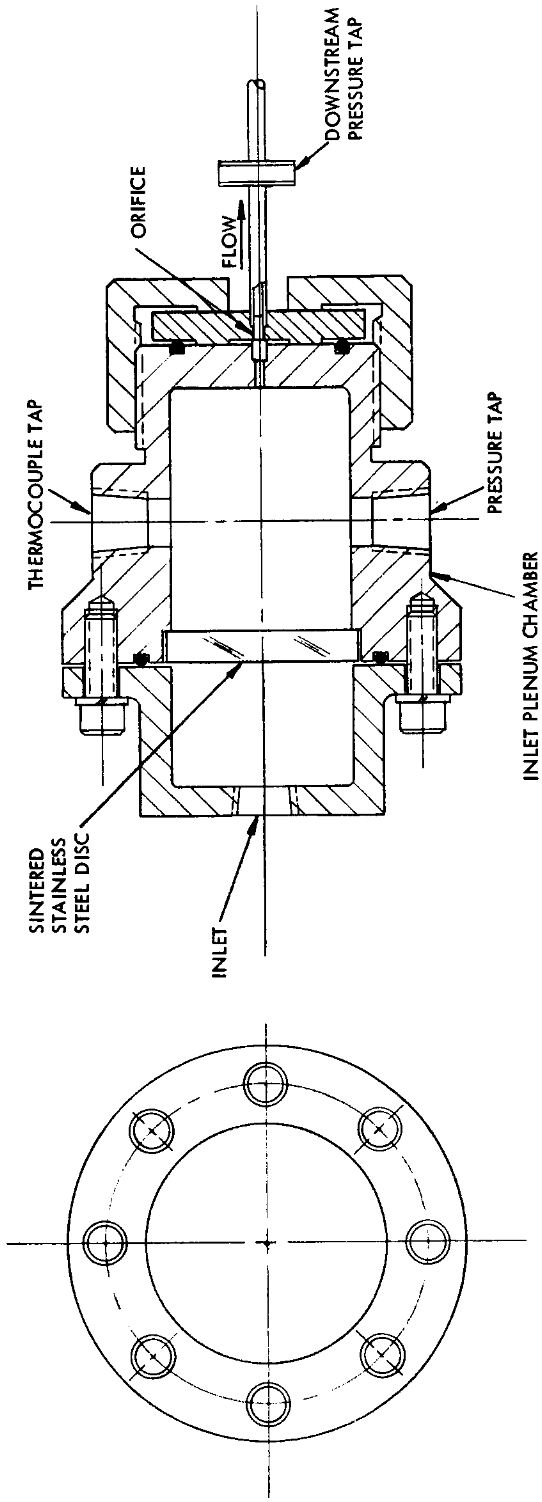


Figure A 8.3 Orifice Test Fixture

measure the flow is a sonic orifice which was calibrated against an NBS calibrated wet test meter.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Utilizing the test parameters described under 5.4, the pressure coefficient (C), defined as:

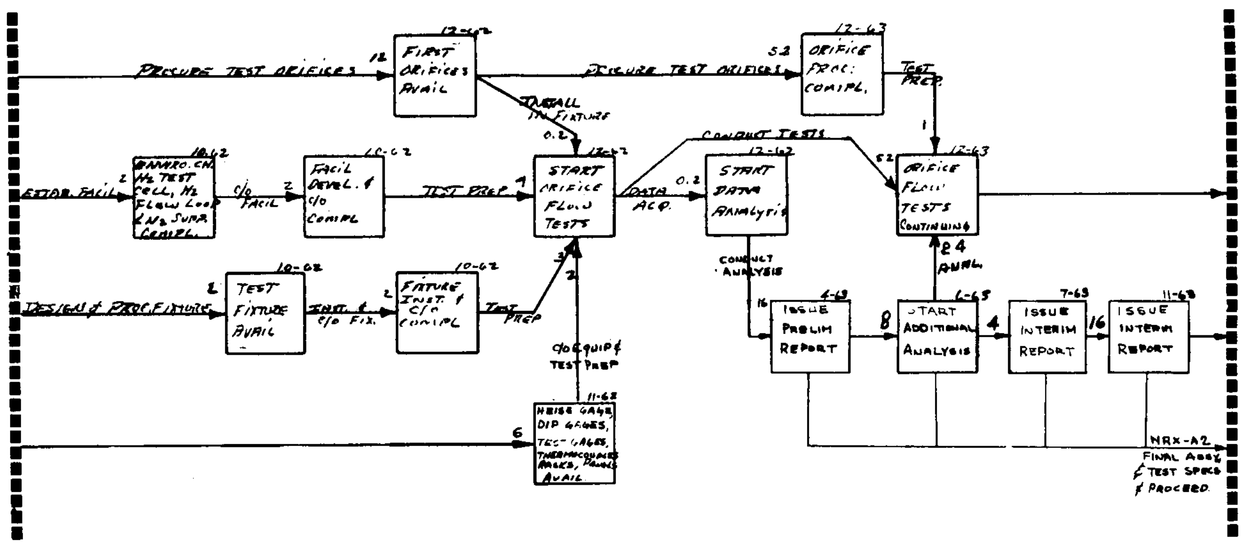
$$C = \frac{2\,g\,(\Delta P)}{\rho\,V^2}$$

can be calculated where:

C	=	pressure drop coefficient (dimensionless)
g	=	gravitiational constant (ft/sec^2)
ΔP	=	static pressure drop across the component (lbs/ft^2)
ρ	=	density of the working fluid (lbs/ft^3)
V	=	velocity of hydrogen in the component flow restriction (ft/sec)

Correlations of the pressure coefficient with flow parameter and geometry must be established. Geometry includes roundness of hole entrance profile, surface finish of hole, diameter tolerance, cluster plate proximity and alignment, flow hole eccentricity, and channel diameter. These data will establish the orifice requirements for the reactor.

6.2 The methodology developed for calibrating orifices in these tests will be translated into quality control standards for the inspection of all incoming production orifices. Maximum and minimum orifices will establish the tolerance band for each nominal size on high speed production testers.



A 5 - FUEL ELEMENT ORIFICE FLOW TESTS

A8
4-8-63

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 9 FUEL CLUSTER ASSEMBLY MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: A 9 DATE: 3-30-63

2. TITLE: FUEL CLUSTER ASSEMBLY MECHANICAL TESTS

3. PURPOSE:

The purpose of the test is to discover any malfunction of the assembled parts of a full-length fuel cluster when subjected to shock and vibration at room temperatures. Determination of damping and of constraints developed by associated hardware on the fuel cluster will provide a better understanding of the motions and resonant frequencies that are induced by shock and vibration. This information will aid in the development of the analytical model used for vibration analysis of core assemblies.

4. REQUIRED DESIGN DATA:

4.1 Determine permissible limits of shock and vibration G loads and amplitudes.

4.2 Determine the maximum permissible negative acceleration loading of the core.

4.3 Determine the "weak-link" components in the design, so that overall reliability can be improved by concentrating effort in the regions of lowest reliability.

4.4 Establish acceptable dimensional tolerance limits for elements.

Engineer: John J. Schreiber

Approved: [illegible]

5. TEST PLAN:

5.1 Description - The test rig will be approximately 5 feet in length and 1 foot in diameter. It will be capable of supporting a full-length fuel cluster surrounded by 6 simulated satellite clusters in a manner similar to that in the actual core assembly. The only difference will be in the interaction of adjacent clusters and lateral supports due to the abbreviated diameter of the fuel cluster being observed. An electrodynamic shaker will be used to induce vibrations. A drop-type shock machine will be used for the shock portion of the test.

5.2 Components Under Test - The various components under investigation will be the full-length fuel module with all of its associated supporting hardware, along with certain selected off-dimension parts.

5.3 Experimental Set-Up - The experimental test set-up will basically consist of a simulated section of the top support plate; the appended fuel cluster with its associated hardware; simulated adjacent clusters and lateral supports; and the overal frame, which supports this array and is capable of being affixed to the shaker and drop tables.

5.4 Test Parameters - Test parameters will be "g" levels, frequencies and amplitudes of vibration; pulse height and duration during shock tests, fuel element clearances, and relative motion of support blocks, fuel elements and other cluster hardware.

5.5 Instrumentation and Data Acquisition - Accelerometers will be used to determine cluster response and relative motions of the various parts. Strain gages will be used, where feasible, to determine strain distributions along the length of the elements in the center fuel cluster under various levels and frequencies. Where required, displacement transducers will be used also to monitor relative motion of parts. Continuous recording of all data will be provided.

6. DATA UTILIZATION:

The data obtained from the fuel element cluster assembly tests will be used to:

6.1 Establish acceptable dimensional tolerance limits for elements.

6.2 Establish permissible limits of shock and vibration frequencies and amplitudes, based on extreme tolerance conditions (i.e., an undersize element).

6.3 Determine the maximum radial loading from lateral support springs and radial pressure differences that will still allow relative axial motion between clusters and elements.

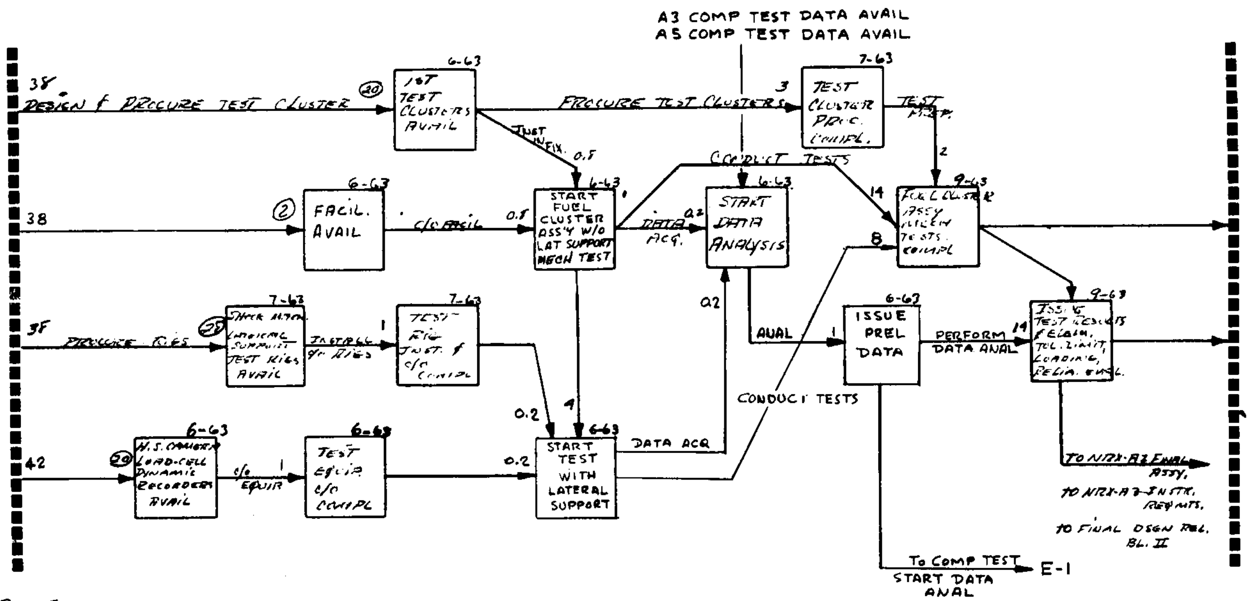
6.4 Establish the reliability improvement which can be obtained by an interlocking support design.

6.5 Determine the maximum permissible negative acceleration loading of the core.

6.6 Determine the maximum permissible lateral shift of the cluster assemblies relative to the core support plate and the lateral flexibility for use in the design of lateral support.

6.7 Determine the "weak link" components in the design, so that overall reliability can be improved by concentrating design effort in regions of lowest reliability.

6.8 Determine internal damping and flexibilities for the analytical model used for vibration analysis.



A 9- FUEL CLUSTER ASSEMBLY MECHANICAL TESTS

A9

4-8-63

TEST SPECIFICATION

A 10 FUEL CLUSTER HIGH TEMPERATURE TEST

REVISION NO: 1

1. TEST NUMBER: A-10 DATE: 3/30/63

2. TITLE: FUEL CLUSTER HIGH TEMPERATURE TEST

3. PURPOSE:

To thermally, hydraulically and mechanically test an integrated fuel cluster assembly under hot operations conditions.

4. REQUIRED DESIGN DATA:

4.1 Determine the weight loss of cluster components under simulated hot operating conditions, and determine changes in dimension and physical condition of the fuel element externals.

4.2 Determine the flow, pressure and temperature distribution in a single cluster under hot conditions.

4.3 Determine the effects of flow and heat maldistributions and channel blockage in the cluster.

4.4 An integrated thermal, mechanical and corrosion test of the support block assembly.

5. TEST PLAN:

5.1 Description - The fuel clusters are suspended by standard reactor hardware in the center of a vertical pressure vessel. Hydrogen gas flows through

Engineer: W. J. Havener

Approved: E. A. DeZubay

the holes in the elements of the cluster and is heated by a direct current supply. The specific design of the heat addition system has not been completed as yet. The cluster exit gas temperature and pressure will be maintained at reactor design conditions.

5.2 Component Under Test - Complete fuel assemblies including fuel elements, unfueled center hexagonal element tie rod, pyro-graphite sleeves, bottom support block, end cone, tie rod holder, plate assembly and positioning spring.

5.3 Experimental Set-Up - The cluster is installed in the center of a vertical water cooled pressure vessel. Gaseous hydrogen flows through the holes of the elements of the cluster and a helium atmosphere is maintained around the cluster. A maximum power input of 2.8 MW is available. The hot gas is discharged into a water cooled heat exchanger, then filtered and finally flared and vented to the atmosphere. A pneumatic control system permits varying the flow and pressure as required by the test and the electrical power controls permit varying the temperature and rate at which power is applied to the cluster. All major test parameters are recorded for data analysis.

5.4 Test Parameters

Cluster Exit Gas Pressure	550 psig
Cluster Exit Gas Temperature	$\leq 4500^{\circ}R$
Hydrogen Mass Flow	Maximum .20 pps
Time at Temperature	15 Minutes

5.5 Instrumentation and Data Acquisition

5.5.1 Physical dimension of each element is measured before and after each test.

5.5.2 Hole sizes are measured by air flow and taper gauges.

5.5.3 Pressures and pressure drops are measured by bellows type instrument and transmitted to pneumatic recorders.

5.5.4 Temperature is measured by thermocouples. Iron constantan and chromel-alumel thermocouples are used for water temperatures and low gas temperatures are recorded on strip chart recorders. High gas temperatures, such as cluster exit temperatures, are measured with tungsten/tungsten - 26% rhenium thermocouples. A sonic probe as described in Test Specification A 2-1 may also be used. A hollow tie rod is used with thermocouples along its length to obtain its temperature.

5.5.5 Vibration transducers are used at the cold end of the cluster to detect tie rod vibration.

5.5.6 Cluster sleeve surface temperature is determined by optical pyrometry and recorded by radimatics.

5.5.7 Flow is measured by a sharp edge orifice and differential pressure cell. The differential pressure is transmitted to a pneumatic recorder with square root extraction.

6. ANALYSIS AND DATA UTILIZATION:

The data from this test will be used to substantiate the basic thermal and mechanical design of the fuel cluster, particularly the tie rod and support block. Particular problem areas to which the data will be applicable are:

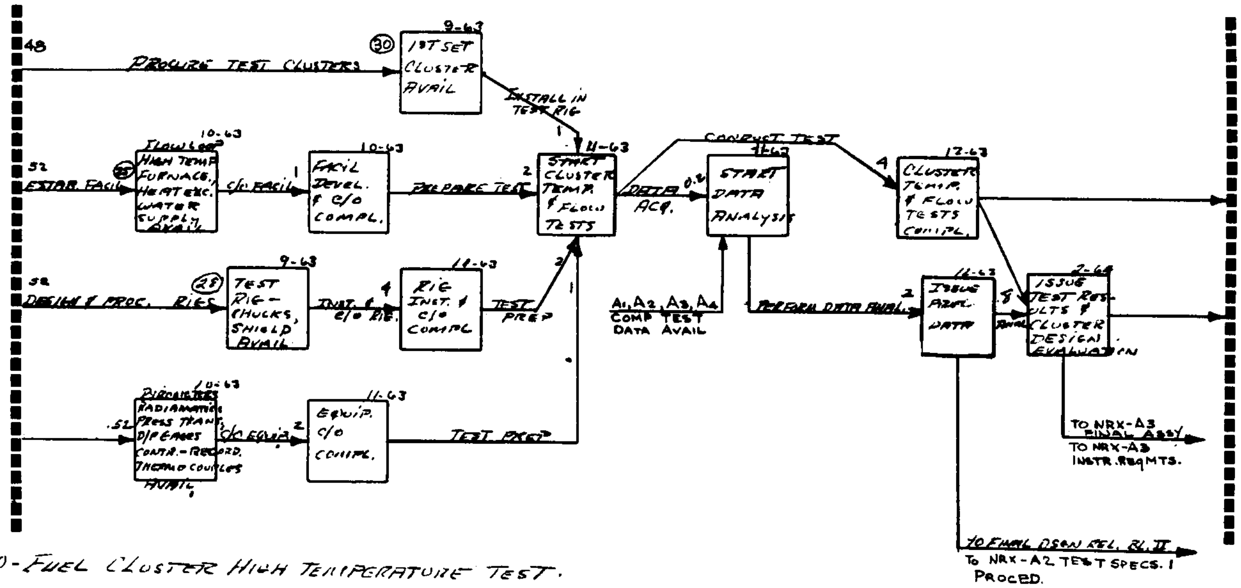
a) Net heat addition to the tie rod coolant through the pyrolytic carbon liner, both when intact and after intentional defection.

b) Flow balance of the tie rod channel (vs. the fuel) with combined effects of heat addition, impedance of centering bushing, channel frictional losses, and cone support.

d) Thermal stresses in support blocks under conditions of unbalanced heat generation in the fuel elements of the cluster.

e) Effects of leakage between elements on corrosion and thermal gradients in the fueled and unfueled elements.

Astronuclear



A10-FUEL CLUSTER HIGH TEMPERATURE TEST.

A10
4-8-63

CONFID[redacted]
RE[redacted]
At[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 11 FLOW INDUCED VIBRATION TEST

REVISION NO: 1

1. TEST NUMBER: A 11 DATE: 3/30/63

2. TITLE: FLOW INDUCED VIBRATION TEST

3. PURPOSE:

To flow test a NRX-A reactor prototype core assembly to investigate and evaluate the types of vibrations which may result from hydrogen coolant flow phenomena and determine the effectiveness of the designed lateral support and seal systems to reduce or eliminate these vibrations in order to insure structural integrity of the core.

4. REQUIRED DESIGN DATA:

4.1 Determine vibration amplitudes and frequencies for various flow conditions.

4.2 Determine the type and degree of constraint or seal conditions required to minimize or reduce these vibrations.

4.3 Determine the environmental conditions which will exist for the test conditions.

5. TEST PLAN:

5.1 Description - Testing will be accomplished by flowing hydrogen gas through an instrumented seven cluster reactor prototype core. The core will be assembled using reactor grade hardware and fitted within a pressure vessel containing a simulated lateral support and seal system, inner reflector, top support plate,

Engineer: J. D. Holmgren

Approved: E. A. De Zubay

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic ~~Energy Act - 1954~~

support rings, and diffuser or shield. The test equipment will be positioned such that the core will be mounted in a vertical position to achieve a downward or upward firing configuration.

The vibration tests will be of short duration and will include specified pressure, temperature and flow histories. Various types of instrumentation will be utilized to measure the degree and mode of vibrations which may be induced in the fuel element clusters as a result of the selected flow conditions. Comparison will be made utilizing different cores, various support and seal configurations and flow conditions.

5.2 Components Under Test - Three different reactor prototype cores will be evaluated. The first core will be utilized for preliminary shake-down tests and will consist of unfueled, uncoated, fuel elements (graphite) and graphite filler strips without pyro-tile. The second core will be similar to the first with the exception of using fueled and coated fuel elements (natural or depleted uranium). In addition, the filler strips will be made with commercial pyro-tile inserts. The third core assembly will be similar to the second core.

Various test core geometries and orificing schedules will be evaluated as a part of the vibration test program. Changes in core geometries will primarily reflect planned, fixed openings between fuel elements or fuel cluster assemblies. These models will be tested with an orificed core as established by the fluid flow multi-channel analysis digital computer program. The orificing schedule for the first core will be based on fuel clusters situated in the center of the reactor core and will essentially utilize 0.060" orifices. Subsequent cores will utilize orificing schedules designed to compare fueled and unfueled cores located in the center of the reactor as well as positions adjacent to the inner reflector. Plugged core tests may be made in order to evaluate the effects of hydrogen flow between the fuel elements and between the filler strips and lateral support and seal rings.

The initial lateral support system to be tested will be a simulated (smaller diameter) NRX-A design and will include the complete complement of 18 segmented rings. Loading of the individual segments will be accomplished using pneumatic pistons or a combination of pistons and flat springs. The circumferentially located pistons on each ring will be manifolded in order to obtain different loads on each seal ring. Leads from each manifold to an external control will provide the flexibility to change seal loading without complete disassembly of the test equipment. Subsequent support and seal systems to be tested will follow reactor design requirements.

5.3 Experimental Set-Up - The flow vibration tests will be carried out in a new hydrogen facility located at the Westinghouse Waltz Mill test site. This test facility will have a capability for carrying out high flow rate hydrogen test programs. The test facilities will include a partially buried, open front test cell, a remotely located tank farm for storage of gaseous and cryogenic fluids, and a remotely located control room to carry out test operations. Testing of the flow vibration apparatus will be essentially a blow-down type operation, and as such, the hydrogen facilities will consist essentially of a gas storage tank, process piping with appropriate flow control valves and a discharge or vent stack.

5.4 Test Parameters - The initial vibration tests will be made using nitrogen. These tests will be essentially shake-down tests to evaluate equipment and instrumentation performance. On completion of the nigrogen tests, hydrogen flow testing will be initiated. The first series of hydrogen tests will follow the reactor start-up schedule and will be carried to nominal design, hydrogen flows. These tests will be followed with a more rapid step function pressure build-up. Succeeding tests will be based on selected, fueled cores and the test conditions will be dictated by previous results.

Test conditions utilizing hydrogen will include:

5.4.1	Gas Temperatures	140 to 540°R
5.4.2	Gas Pressures	0 to 700 psig
5.4.3	Gas Flow Rate	0.0 to 2 lbs/sec

The length of the test will be determined by the capacity of the gas storage facility. For ambient temperature runs at a mass flow rate of 2 lbs/sec the test duration will be in the order of thirty seconds. When the gas is cooled to liquid nitrogen temperatures, the testing time will be extended to approximately 120 seconds.

5.5 Instrumentation and Data Acquisition - The prototype test core will be instrumented with tri-axial accelerometers, linear displacement gauges, and strain gauges. It is planned to locate the accelerometers on the tie rods or bottom support blocks and place the displacement gauges between clusters and between the outer clusters and inner reflector. Strain gauges will be mounted on the fuel elements. Frequency calibrated pressure transducers will be located at various positions including the gas inlet, the dome end support plate plenum, the nozzle end support plate plenum and the core discharge or nozzle plenum. In addition, high pressure microphones will be placed in the gas inlet and discharge area. This instrumentation should provide information concerning core vibration, core movement in relation to the inner reflector and clusters, pressure fluctuations in the test fluid at various positions and acoustic effects in the hydrogen stream. In addition, high speed photographic techniques will be utilized to visually determine the behavior of the bottom support blocks and this information will be correlated with the data as determined by the previously cited instrumentation.

The data acquisition system includes a 24 channel high speed oscillograph recorder with provisions for subsequent addition of a multiplexer and tape recording facility.. This system will provide the necessary flexibility for obtaining visual recorders as well as a capability for rapid data reduction.

6. ANALYSIS AND DATA UTILIZATION:

The data from the flow vibration tests will be evaluated to determine core vibration behavior with respect to various lateral support and seal constraints, core models, and flow environments. Required information includes:

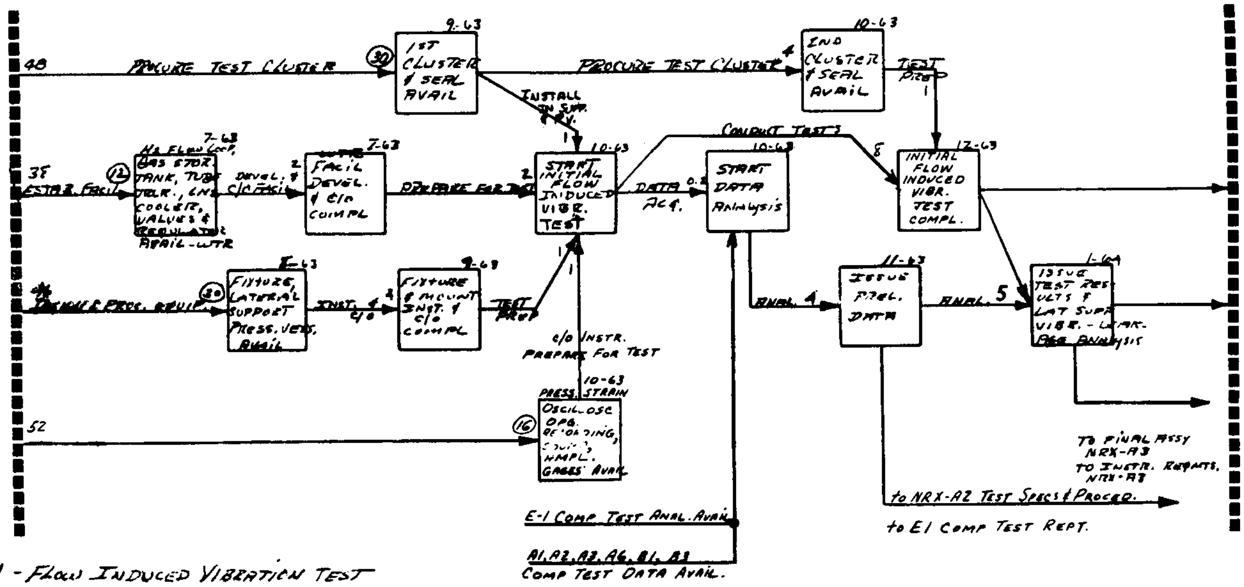
6.1 What vibration frequencies are obtainable under given flow conditions

6.2 What restraints will eliminate them

6.3 What type of damping can limit the amplitude

6.4 What are the basic flow dynamics which will yield an insight into the mechanisms of exciting these vibrations

The flow vibration test results will be correlated and compared to information obtained from full scale reactor hot and cold tests as well as other lateral support and seal tests.



A 11 - Flow Induced Vibration Test

A11
4-8-63

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

A 12 LAMINAR FLOW INSTABILITIES

REVISION NO: 1

DATE: 3/30/63

1. TEST NUMBER: A 12

2. TITLE: LAMINAR FLOW INSTABILITIES

3. PURPOSE:

Multivalued flow can theoretically exist for a specified pressure drop in the laminar flow regime. These multivalued flows could lead to flow instabilities capable of exciting reactor component vibrations or causing flow starvation in some channels, especially during retreat, pulse cooling or reactor shut-down.

4. REQUIRED DESIGN DATA:

4.1 Experimentally verify flow instabilities through parallel tubes during laminar flow.

4.2 Determine the parameters which delineate domains of flow instabilities.

4.3 Provide a correlation of experimental and analytic data.

5. TEST PLAN:

5.1 Description - The flow characteristics of a single tube will be measured. A single tube with uniform heat input (resistance heating) will initially be used at various flows and power levels to determine a multivalued flow, pressure drop relation as predicted from theoretical results. Once this is determined, a multiplicity of tubes progressively increasing in number from two to five

---

Engineer: E. A. DeZubay

Approved: E. A. DeZubay

will be connected in parallel. These will be instrumented so that phase relations in pressure and flow histories can be determined.

5.2 Components Under Test - The experimental equipment will simulate the flow conditions expected in fuel element passages and will include the effects of fuel element orifices.

5.3 Experimental Set-Up - A regulated gas supply will provide the working medium to a gas plenum chamber which will supply the gas flow passages which will be in parallel flow. Flow and pressure measurements will be made on a temporal basis. In this way flow and pressure histories of individual tubes will be available for comparison with analytic data. Heating of individual tubes will be done by individually adjustable power inputs.

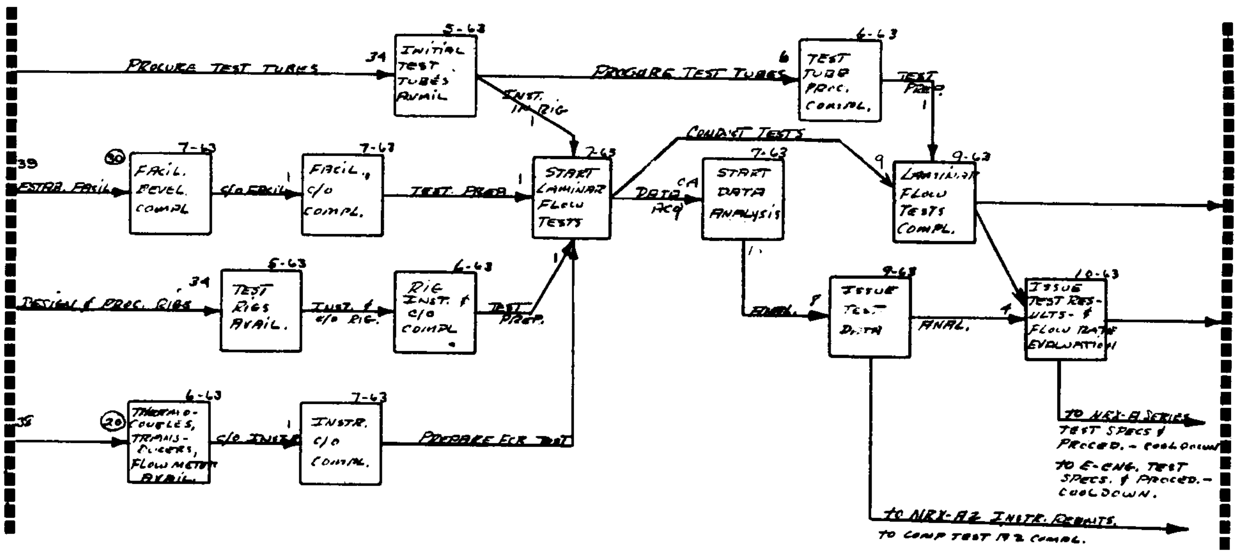
5.4 Test Parameters -

5.4.1	Hydrogen Flows	0.01 to 1.0 pph
5.4.2	Pressure Levels	1 to 100 psig
5.4.3	Temperature Levels	60 to 2500°R

5.5 Instrumentation and Data Acquisition - Pressure transducers and hot wire anemometers will be used to acquire and record time dependent data on a recording oscillograph. Steady state conditions such as inlet temperature, and power levels will be acquired on millivolt recorders.

6. ANALYSIS AND DATA UTILIZATION:

The data will verify laminar flow instability problems and locate the regimes where stable flow is possible.



A12 - LAMINAR FLOW INSTABILITIES

A12
4-8-63

TEST SPECIFICATION

B 1 LATERAL SUPPORT SPRING MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: B 1 DATE: 3/30/63

2. TITLE: LATERAL SUPPORT SPRING MECHANICAL TESTS

3. PURPOSE:

A system of spring-loaded Lateral Supports is required to support lateral loads from the Reactor Core. Static and dynamic performance of individual Lateral Supports and multiple assemblies of Lateral Supports must be evaluated at room temperature, prior to testing at operating temperatures.

4. REQUIRED DESIGN DATA:

4.1 Back-Up Design

The lateral support system in the Back-Up Design consists of spring-loaded graphite blocks, each provided with a pyrolytic graphite face, curved to fit the core radius. The blocks and springs are housed in the inner reflector as shown in Figure B 1.1.

4.2 Determine the deterioration in mechanical properties of two candidate Lateral Support Spring configurations after 100,000 cycles at 10 cps and 0.526 inch peak to peak amplitude. The candidate configurations are a single helical spring per lateral support and two helical springs per lateral support, consisting of a soft spring and a hard spring to form a non-linear spring system.

Engineer: John C. Schmertz

Approved: [signature]

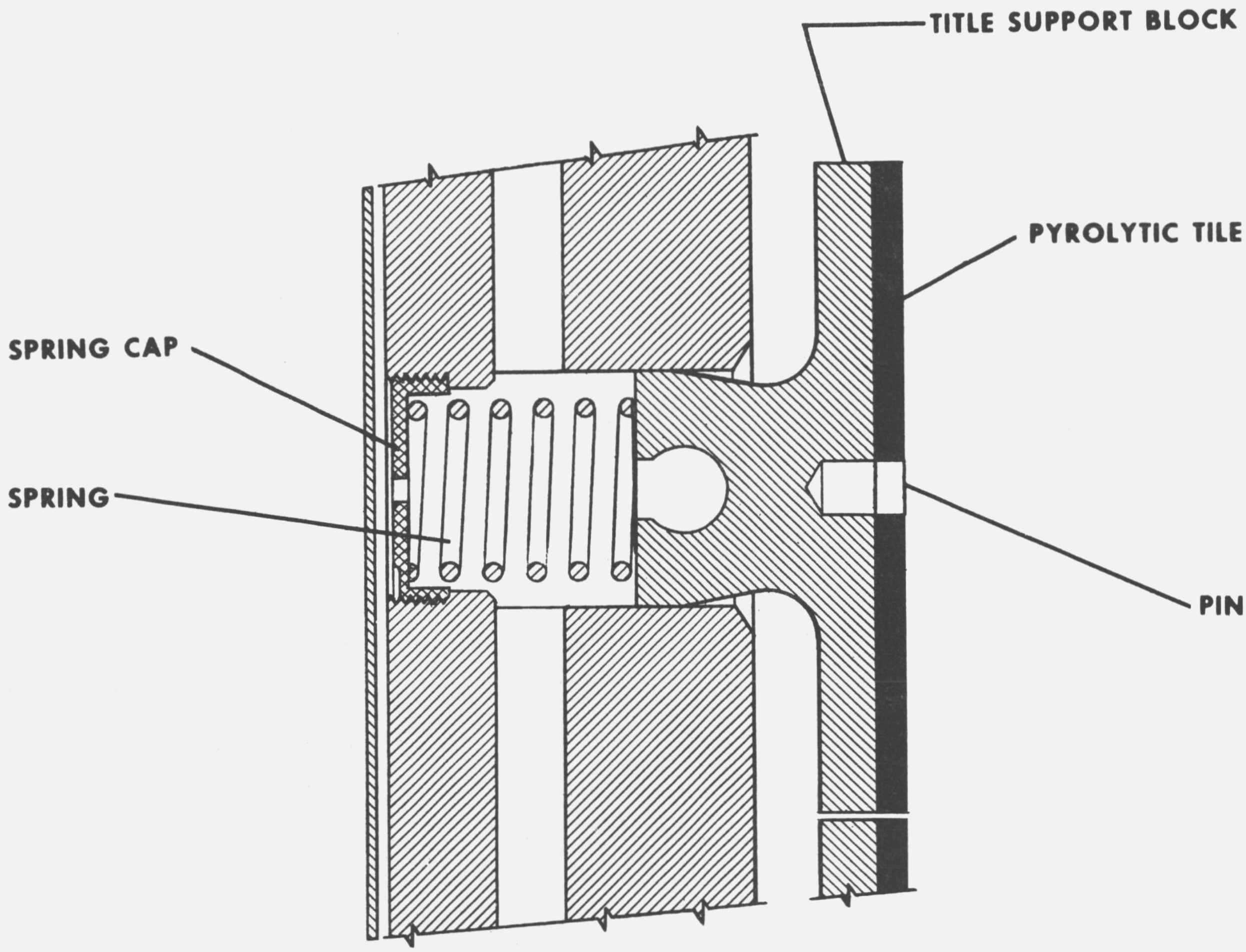


Figure B 1-1 Lateral Support

4.3 Determine the mechanism of interaction between the curved face of a spring-loaded lateral support block and the core surface due to relative motion in various directions between the core and the inner reflector. Determine the amount of wear of the support block.

4.4 Determine behavior of multiple assemblies of the Back-Up Design to note how they interact with the core and with each other.

4.5 Present Design

The lateral support system in the present design consists of plunger-loaded seal strips, curved to fit the core radius. The plungers are in turn loaded by leaf springs. The seal strips, plungers and leaf springs are housed in the inner reflector, as shown in Figure B 1.2.

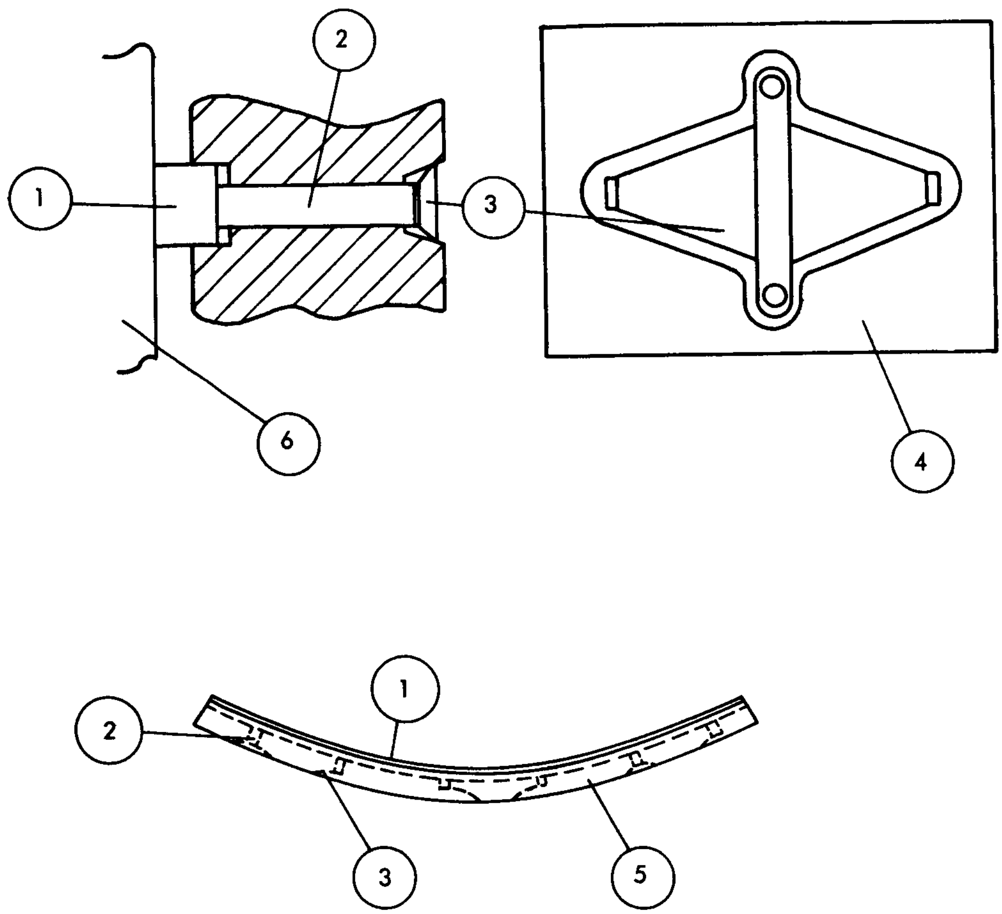
4.6 Determine the deterioration in mechanical properties of the leaf spring configurations after 100,000 cycles at 10 cps.

4.7 Determine the mechanism of interaction between the inner reflector, springs, plungers, seal strips, and core due to relative motion between the core and the inner reflector. Ascertain amount of wear and deterioration of each element.

5. TEST PLAN:

5.1 Description

All but one of the B 1 Tests will be performed on the existing rig shown in Figure B 1.3. The remaining B 1 Test, which is intended to supply the data requirements outlined in paragraph 4.2.2, will require a new test rig to accommodate the larger test specimen. The probable configuration of this rig is shown in Figure B 1.4.



1. SEAL STRIP
2. PLUNGER
3. LEAF SPRING
4. SIMULATED PORTION OF INNER REFLECTOR
5. SIMULATED PORTION OF INNER REFLECTOR
6. CORE

560915

Figure B 1-2 Lateral Support Test Specimens

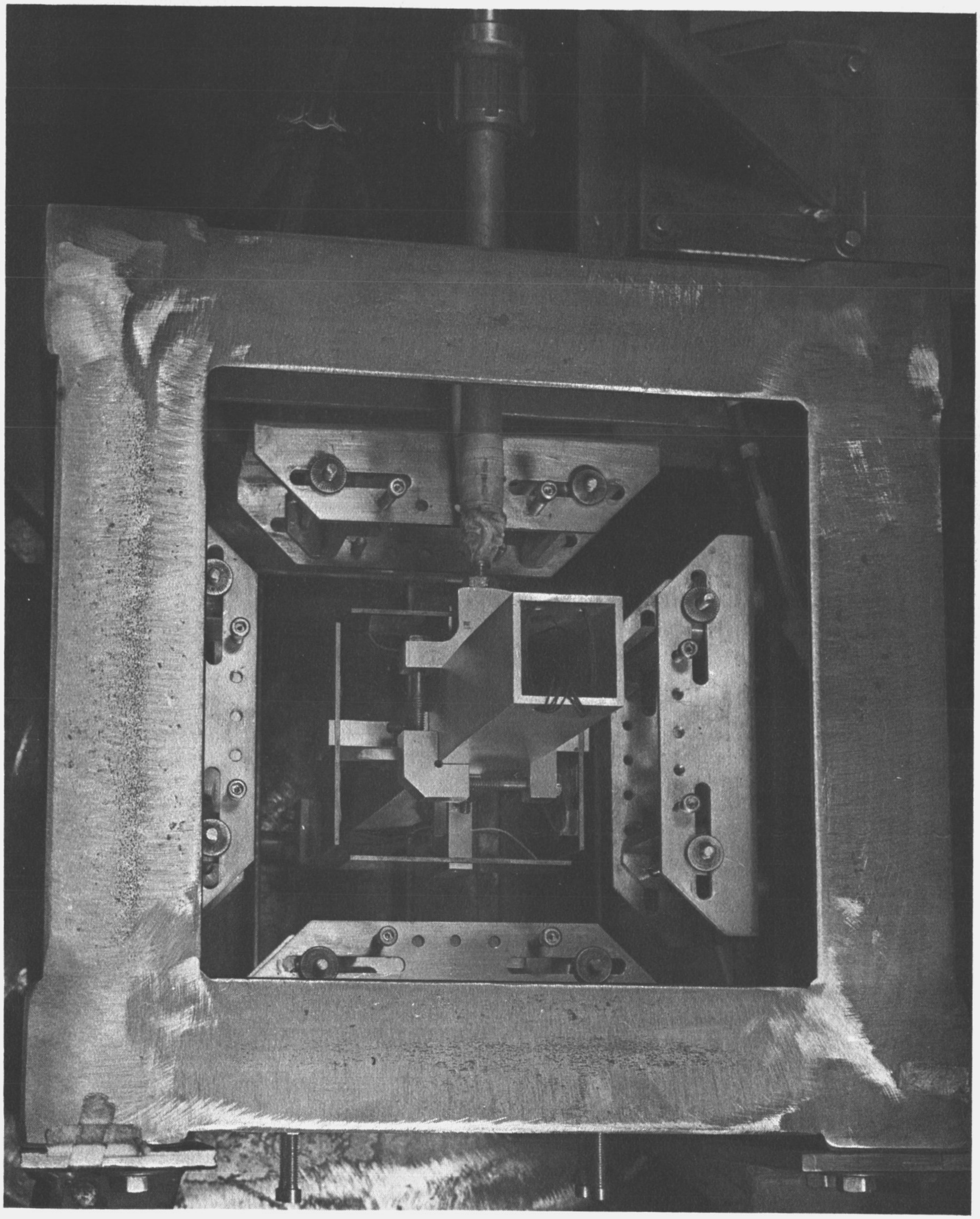


Figure B 1·3 Lateral Support Test Rig

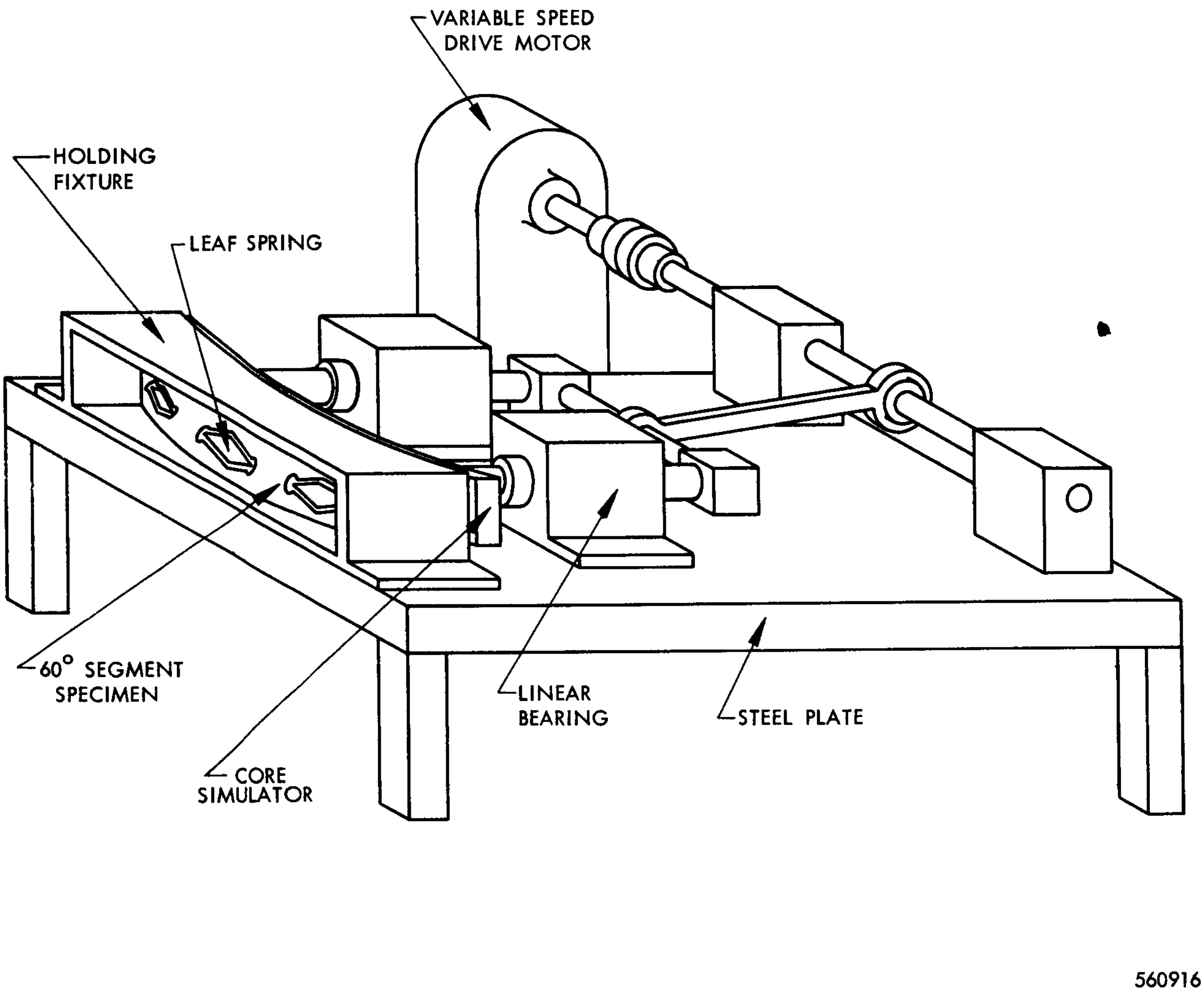


Figure B 1·4 60° Inner Reflector – Lateral Support Test Rig

The specimens to be tested are secured to the test rig by holding fixtures, and dynamically loaded by a constant stroke push-rod mechanism which simulates possible motion of the reactor core.

5.2 Components Under Test

The assembly shown in Figure B 1.1 includes all the components to be tested to supply the B 1 data requirements of the Back-Up Design. The single helical spring is shown installed in the inner reflector, and the alternate non-linear spring system is shown below it. The assembly shown in Figure B 1.2 includes all the components to be tested to supply the B 1 data requirement of the present design.

5.3 Experimental Set-Up - Back-Up Design

The experimental set-up used for the B 1 test of the Back-Up Design is shown in Figure B 1.3. The load on each lateral support spring is measured by means of calibrated test plates provided with SR-4 strain gages. The plates are calibrated by recording the strain gage readings corresponding to known applied loads, and plotting a load versus strain calibration curve. During tests, the strain is measured and the corresponding load is found from the calibration curve. The motion of the lateral support block system is prescribed by the amplitude of the push-rod displacement.

The test for the mechanism of interaction between the curved face of the lateral support block and the core surface will be accomplished by substituting a graphite block with curved sides for the test plate assembly on the push-rod. The motion of the graphite block, as prescribed by the push-rod motion, will simulate the action of the core against the curved faces of the lateral supports.

For all the above tests, the loading will be transmitted by the push-rod at 0°, 30° and 45° from the line of perpendicularity.

During all tests the specimens will be periodically removed from the test rig and weighed, photographed, and static tested.

5.4 Experimental Set-Up - Present Design

For the B 1 Test of the Present Design lateral supports, both the test rig shown in Figure B 1.3 and the rig shown in Figure B 1.4 will be used. The leaf spring and plunger assembly housed in the simulated portion of the inner reflector (Item 4 shown in Figure B 1.2) will be tested in the rig shown in Figure B 1.3, using the calibrated test plates provided with SR-4 strain gages. The direction of drive of the push-rod shall be varied from 0°, 30°, 45° from the line of perpendicularity.

The entire assembly shown housed in the simulated portion of the inner reflector (Item 5 of Figure B 1.2) will be tested in the rig shown in Figure B 1.4.

During all tests the specimens will be periodically removed from the test rig and weighed, photographed, and static tested.

5.5 Test Parameters

Push-Rod Travel	$\pm$ .263 in.
Frequency	10 cps
Number of Cycles	100,000
Spring Adjustment	75 lb./ Spring (At max. push-rod travel)

5.6 Instrumentation and Data Acquisition

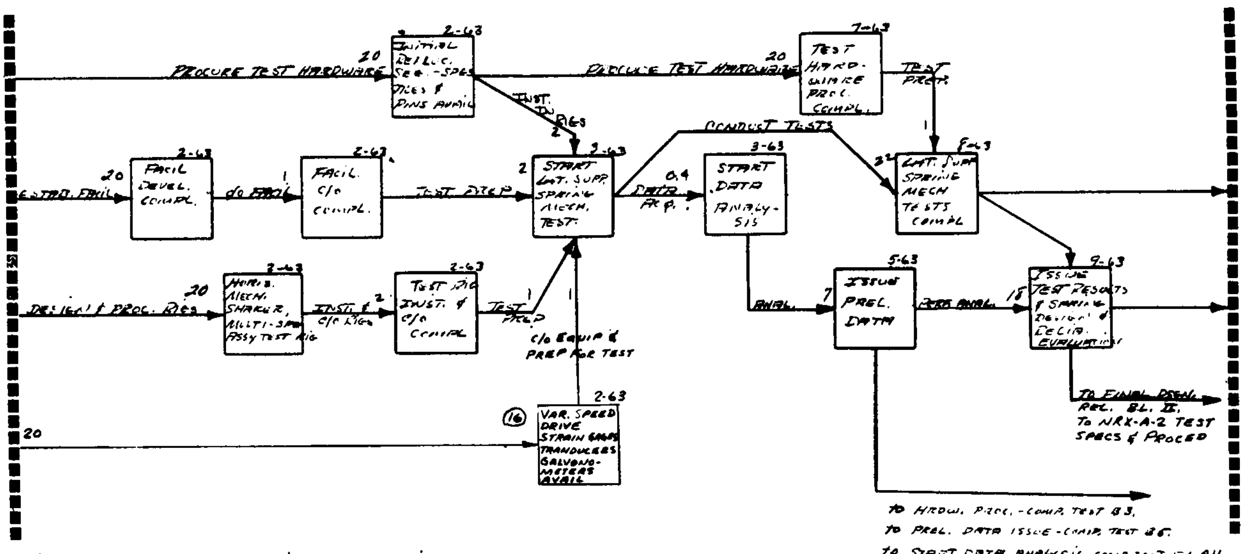
The output of each strain gage is automatically plotted against time, using a Brush Recorder. High-speed photography will be used to obtain a visual record of the behavior of the components at 10 cps.

6. ANALYSIS AND DATA UTILIZATION

The test results obtained will be used to establish proper mechanical functioning of the specimens at 10 cps and to evaluate candidate specimens from the standpoint of strength, repeatability, and durability.

~~CONFIDENTIAL~~
RESTRICTED ~~DATA~~
~~Atomic Energy Act~~ 1954

Astronuclear



B 1 - LATERAL SUPPORT SPRING MECHANICAL TESTS

B1
4-8-63

~~CONFIDENTIAL~~
~~RESTRICTED~~ DATA
Atomic Energy ~~Act 1954~~

CON[redacted]
R[redacted]
A[redacted]954

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

B 2 LATERAL SUPPORT BLOCK AND PYRO TILE SUBASSEMBLY TEST

REVISION NO: 1

DATE: 3/30/63

1. TEST NUMBER: B 2

2. TITLE: LATERAL SUPPORT BLOCK AND PYRO TILE SUBASSEMBLY TESTS

3. PURPOSE:

Pyrolytic graphite tiles are used in the reactor for thermal insulation of the core. High thermal gradients will tend to bow the pyro-tiles which are restricted by the lateral support spring loads. Investigations are to be conducted on a section of the present lateral support design and also on an alternate support block design. These investigations are to determine if the pyro-tiles, filler strips, seal sections, and plungers can properly function under design operating conditions of temperatures, pressures, spring loads, and hydrogen flow.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine the effect of the high temperature gradients on the pyrolytic tile (i.e., will the pyro-tile bow or remain attached to the support block of filler strips).

4.2 Find the various gradients and stresses present in the lateral support subassembly under simulated conditions.

4.3 Test various graphite cements to determine if they will hold up under temperature, pressure hydrogen flow, thermal shock and will adequately hold the pyro-tile in place.

Engineer: Larry Parsons

Approved: [illegible]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

4.4 Determine the effect of mechanical cycling of the lateral load on the endurance strength of the lateral support subassembly.

4.5 Evaluate thermal shocking of the lateral support subassembly. This will be accomplished by regulating coolant flow and heating element current.

4.6 Evaluate fretting and wear at contacting surfaces. This will be measured by optical inspection and surface finish measurements.

4.7 Evaluate corrosion of graphite by dimensional change, surface condition, and weight change.

4.8 Study creep and physical distortion and/or damage of the system after various periods of simulated service.

5. TEST PLAN:

5.1 Description

The present design (filler strips) of the lateral support assembly and also an alternate design (lateral support blocks) will be tested under simulated conditions. Thermal gradients will be induced to investigate the interaction between the support blocks and pyrolytic tile under mechanical loading. The same pressure vessel will be used in the testing of both lateral support subassemblies. Operating thermal conditions will be duplicated by means of a graphite heating element simulating the core curvature, by the hydrogen gas pressure and flow rate, and by a cooling water flow rate. Spring loads will be simulated by pneumatic diaphragms which control the forces on the lateral support subassembly.

The graphite reactor components and the graphite simulated parts and insulators are assembled in a copper jacket which is split to facilitate assembly. The center of the rig is a graphite heating element machined to mate with the lateral support system. Water-cooled 3/8 inch copper tubing is used for power leads for the heating elements. Instrumentation and water-coolant lines are connected to the copper jacket and the entire assembly is inserted into a stainless steel pressure vessel. Hydrogen gas enters one end of the pressure vessel, flows along the lateral support system, and out the other end of the vessel. See Figure B 2-1.

5.2 Components Under Test

5.2.1 Test of Present Design

The prototype reactor components, or sections of components to be tested are listed below with the drawing number for each component.

Filler Strips, 1 through 27	Dwg. No. 909E401 909E427
Insulating Tile	Dwg. No. 945C657 945C658 945C659 945C699
Seal Segments	Dwg. No. 977D843 977D844 977D845
Lateral Support Plunger	Dwg. No. 963B727

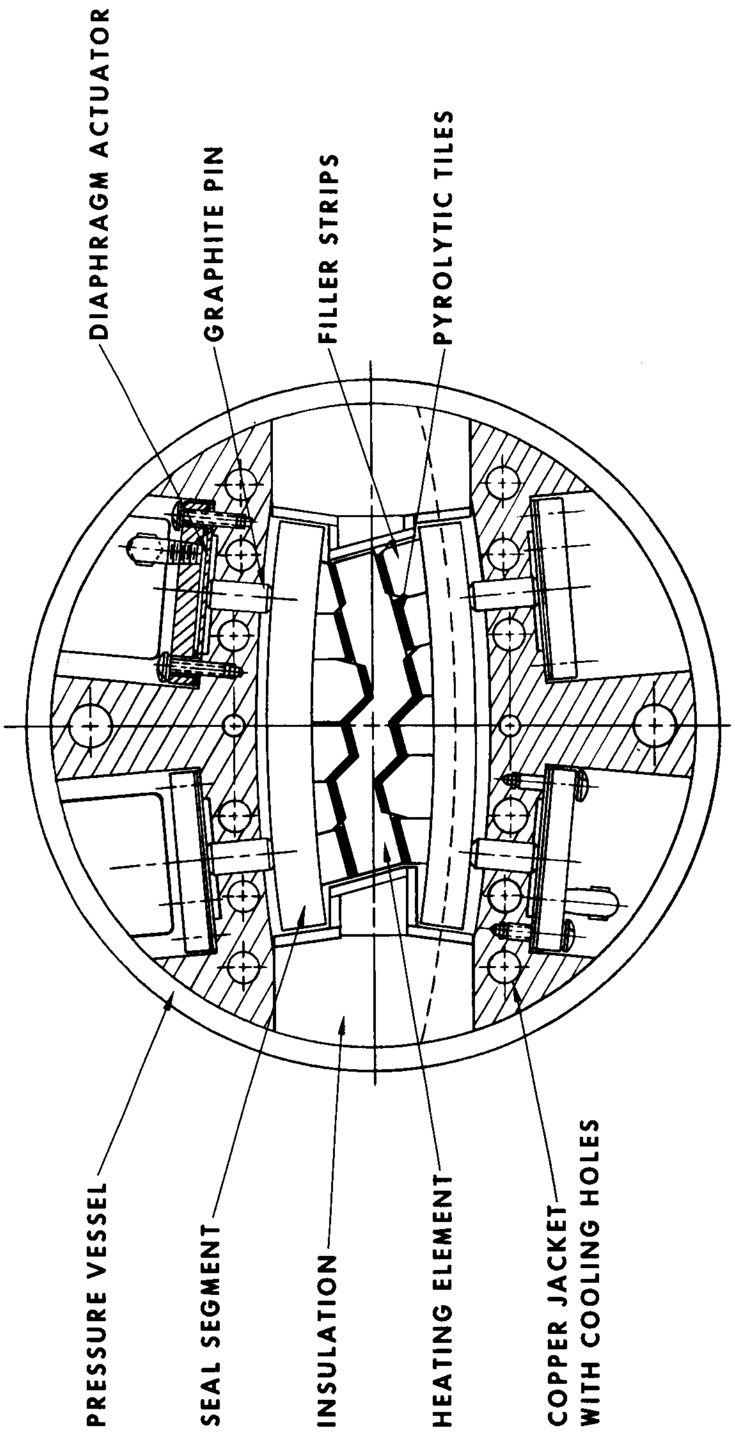
5.2.2 Test of Alternate Design

The prototype components for testing the back-up design are described by the following drawings.

Lateral Support Assembly	Dwg. No. 793C818
Lateral Support Block	Dwg. No. 793C786
Insulating Tile	Dwg. No. 793C783
Lateral Support Pin	Dwg. No. 609B081

5.3 Experimental Set-Up

The pressure vessel and flat heads will be made of 304 stainless steel. Piping, power leads, and instrumentation will come through one head while the other is essentially a permanent head. The simulated reflector (copper) is split to facilitate assembly of the components and to help alleviate thermal stresses. The electrical power leads are water cooled 3/8 inch copper tubing. The graphite simulated core is resistance heated.



500655

Figure B 2-1 Lateral Support Subassembly Test

Cooling water is used to prevent excessive temperatures in the copper block and to help control thermal gradients. Hydrogen enters the removable head and exits through the permanent head.

The temperature will be controlled by the current flow through the graphite heating elements. Steel diaphragms are used to simulate spring loads. The amount of the load is varied by the hydrogen pressure differential across the diaphragm. Hence, the variables which can be set to obtain various gradients in the test assembly are:

1. Coolant water flow rate.
2. Coolant water inlet temperature.
3. Heating element current.
4. Hydrogen gas flow rate.
5. Hydrogen gas inlet temperature.
6. Hydrogen gas pressure.
7. Diaphragm gas pressure.

The coolant water flow rate will be controlled by a valve. The coolant water inlet temperature and the hydrogen gas inlet temperature will be room temperature, but if it proves necessary to vary these temperatures, heat exchangers can be added to obtain the desired temperatures. Heating element current will be regulated by the power supply. The hydrogen gas (or any inert gas) used to actuated the diaphragms will be measured in excess of the pressure in the pressure vessel.

In both lateral support subassemblies, graphite and pyrolytic graphite is used to simulate reactor parts and for thermal insulation.

5.4 Test Parameters

Hydrogen gas pressure	0 - 650 psi
Simulated spring load (diaphragm force)	0 - 65 lb.
Heating element temperature	0 - 4000^{o}R

The inlet coolant water and hydrogen gas will be maintained at ambient temperature unless testing indicates that some other temperature might be more desirable. Coolant water flow rate and the hydrogen gas flow rate will be varied to obtain different thermal gradients.

Calculated thermal gradients will be approximately duplicated in the test rig, and the lateral support scheme will be investigated under expected thermal, mechanical and hydrogen flow conditions.

5.5 Instrumentation and Data Acquisition

These tests are to be conducted under simulated service conditions. Hence, readings or recordings must be kept of all variables. High temperature strain gages will be employed where necessary. The current to the heating element will be measured. High temperature thermocouples will provide temperature readings of the various lateral support components. Pressure gages will read the hydrogen gas inlet and outlet pressure, and the diagram-pressure vessel pressure differential. Flowmeters will measure the coolant water and hydrogen gas flow rates.

6. ANALYSIS AND DATA UTILIZATION

6.1 The test data will either verify or reject the given lateral support system design, and demonstrate its flaws. The data obtained from these tests will be used to:

6.1.1 Provide fatigue data for tiles and lateral support blocks under simulated operating conditions.

6.1.2 Determine the effects of varying temperature and hydrogen flow.

6.1.3 Determine the dimensional stability of the component.

6.1.4 Determine the adequacy of the components under thermal shock.

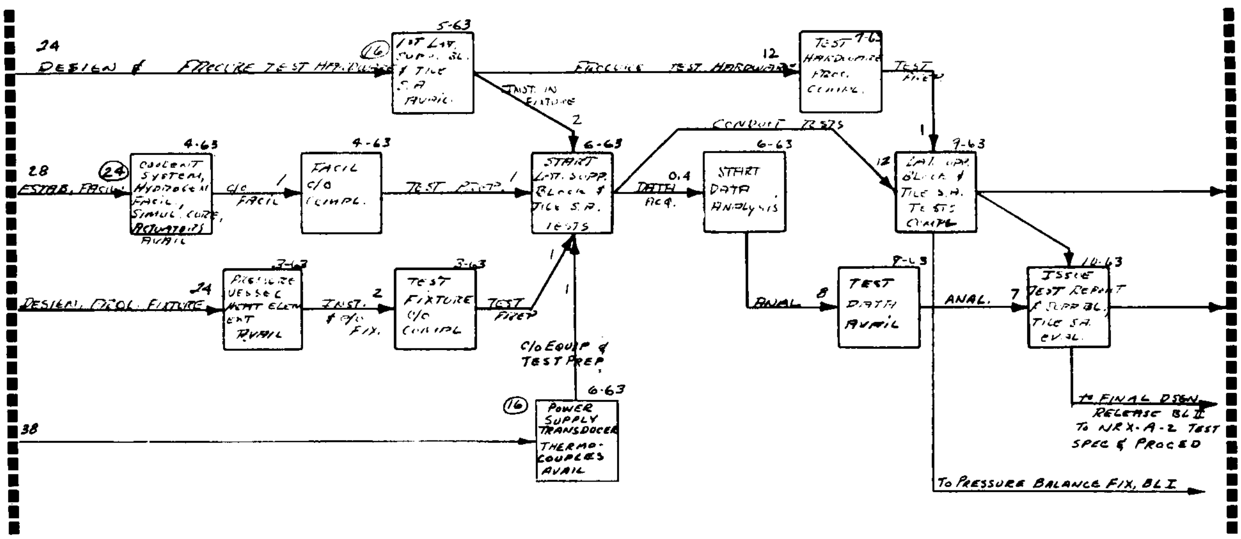
6.1.5 Determine the corrosion rates of a lateral support component and the effect of such corrosion on its strength and deflection characteristics.

6.1.6 Determine the adequacy of various bonding materials for restraining the tiles, and therby, determining the material best suited for this environment.

6.1.7 Determine the effects of temperature gradients in the tile and lateral support subassembly on stress and distortion of these components.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

Astronuclear



B2 - Lateral Support Block & Pyro Tile Subassembly Tests

B2
1-8-63

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

TEST SPECIFICATION

B 3 LATERAL SUPPORT AND SEAL TEST

REVISION NO: 1

1. TEST NUMBER: B 3 DATE: 3/30/63

2. TEST TITLE: LATERAL SUPPORT AND SEAL TEST

3. PURPOSE:

The effectiveness of the reactor lateral support and seal system must be established. This system comprises a complex flow system combining radial flow through the filler strips between the core and the seal annulus, axial flow past the seal segments, and leakage past the spring pins. Suitable models to determine the individual component flow characteristics and pressure losses and the combined effects must be tested. The adequacy of the lateral support system must be determined by component test in order to insure a successful NRX-A test.

4. REQUIRED DESIGN DATA:

4.1 Determination of the loss coefficients for the lateral support and seal system.

4.2 Determination of the adequacy of the mechanical and thermal design of the support and seal system and related parts of the core periphery (seal blocks, pins, springs, inner reflector, filler strips).

5. TEST PLAN:

Engineer: W. J. Havens

Approved: E. A. DeJubay

5.1 Permeability

5.1.1 Description - The diffusion of hydrogen through various types of graphite will be determined by measuring the flow for various pressure differences.

5.1.2 Samples Under Test - Various types of graphite, both plain and impregnated, will be tested. (ATJ, HLM, and ZTA).

5.1.3 Experimental Set-Up - A two chamber experimental device is used to measure the diffusion constant. The two chamber device is separated by a porous disk under investigation. Pressure-temperature histories are maintained at both chambers during the diffusion process. As long as the sum of the mass of both chambers is constant no leakage is evident. The mass-pressure history can be converted to the diffusion constant.

5.1.4 Test Parameters

Initial Pressures	20 - 800 psig
Initial Pressure Differences	15 - 150 psi
Temperature	500 - 1000^{o}R

5.1.5 Instrumentation and Data Acquisition - Pressures and pressure drops are read visually with precision Heise gauges. Leakage flow rates are measured by pressure, volume, temperature relations of the up-stream and downstream areas of the test specimen.

5.2 Single Seal Low Pressure Tests (Isothermal)

5.2.1 Description - The tests consist of four phases.

5.2.1.1 Measurement of axial flow rates past seals with various clearances, pin spring pressures, and gaps between filler strips with various pressure differences.

5.2.1.2 Measurement of radial flow rates past pins and through and past filler strips of various permeabilities and geometries.

5.2.1.3 Measurement of combined flow rates.

5.2.2 Specimens under test: Flat seals, with pins; and flat filler strips.

5.2.3 Experimental Set-Up: A single chamber plastic test piece is used to measure the axial flow rates past a six inch long flat seal segment. Provisions are incorporated in the device to permit variation of the radial and axial clearances between the seal and the barrel. The filler strips are readily replaceable, and various geometries ranging from a solid block to large gaps between the strips will be tested. This plastic test piece will be modified to contain three chambers, each with a separate supply so that the relative radial pressures may be varied to produce flow in either direction. The pressure differences across all components will be measured, and the flow rates into and out of each chamber determined.

5.2.4 Test Parameters:

Inlet Pressure	1.0 - 60 psig
Fluid Temperature	Ambient
Working Fluid	Air and Hydrogen

5.2.5 Instrumentation and Data Acquisition: Pressures are read visually from dial gauges. Pressure drops are measured with water manometers. Flows are measured with calibrated orifice meters.

5.3 Single Seal High Pressure Tests (Isothermal)

5.3.1 Description - The high pressure applicability of the low pressure tests (Section 5.2) will be determined from a sufficient number of selected tests at reactor pressures.

5.3.2 Specimens Under Test: Flat seals with pins, and flat filler strips.

5.3.3 Experimental Set-Up: A multiple chamber pressure test piece will be used to measure the axial and radial flow rates past a nine inch long flat seal segment.

5.3.4 Test Parameters:

Inlet Pressure	1.0 - 700 psig
Fluid Temperature	Ambient
Working Fluid	Air and Hydrogen

5.3.5 Instrumentation and Data Acquisition: Pressures will be read visually from dial gauges. Pressure drops will be measured with pressure transducers. Flows will be measured with calibrated orifice meters.

5.4 Multiple Seal High Pressure Tests (Isothermal)

5.4.1 Description: The effect of many flow resistances in series and parallel combination will be determined.

5.4.2 Specimens under Test: 18 flat seal segments and various full length filler strip geometries.

5.4.3 Experimental Set-Up: A full length flat section of the support and seal system with 18 flat seals will be enclosed in a high pressure, three chamber test piece. The flow rates in all directions may be varied by individual control of the relative radial pressures.

5.4.4 Test Parameters:

Inlet Pressure	1.0 - 700 psig
Fluid Temperature	Ambient
Working Fluid	Air and Hydrogen

5.4.5 Instrumentation and Data Acquisition: The pressures and pressure differences will be measured with pressure transducers, and calibrated orifices will be used to measure the flow rates. All data will be taken on high speed recorders.

5.5 Single Seal Heated Graphite Tests

5.5.1 Description: The influence of heated seals on leakage, the effects of imposed temperature gradients on leakage, and the effects of heated seals on the corrosion and erosion rates will be determined in a single seal heated section with fluid of various temperatures.

5.5.2 Specimens under Test: Flat seal segments and pins, various filler strip geometries.

5.5.3 Experimental Set-Up: A single flat seal segment with two joints, (approximately 9 inches long) supported by pins will be installed in a three chamber high pressure test rig. Provisions will be made for electrically heating the core side of the filler strips and for refrigerating the reflector side of the seal system. The working fluid will be refrigerated or heated. This model will be an upgraded version of the model used in paragraph 5.3.

5.5.4 Test Parameters:

Inlet Pressure	1.0 to 700 psig
Inlet Temperature	140 to 2000°R
Material Temperatures	Variable
Working Fluid	Hydrogen

5.5.5 Instrumentation and Data Acquisition: Pressures and pressure drops measured with Heise gauges and pressure transducers. Flow measurement with calibrated orifices. Temperature measurement with chromel-alumel thermocouples.

5.6 Full Scale Circular Heated Test

5.6.1 Description: The flow rates past several seals (3-6) will be determined when various axial and radial temperature gradients are imposed on a full scale circular model. The influence of mechanical misalignment and the nozzle end seal will also be studied.

5.6.2 Specimens under Test: Full scale circular support and seal system, nozzle end seals.

5.6.3 Experimental Set-Up: A full scale circular test piece of sufficient axial length (9 to 20 inches) to contain 3 to 6 seals will be enclosed in a high pressure vessel. The core side will be electrically heated and the reflector side will be cooled.

5.6.4 Test Parameters:

Inlet Pressure	1.0 to 700 psig
Inlet Temperature	140 to 800°R
Material Temperatures	Variable
Working Fluid	Hydrogen

5.6.5 Instrumentation and Data Acquisition

Pressures and pressure drops measured with Heise gauges and pressure transducers. Flow measurement with calibrated orifices. Temperature measurement with chromel-alumel thermocouples.

5.7 Full Length Heated Sector Tests

5.7.1 Description: The flow past the filler strips and the thermal gradients induced by this flow will be determined.

5.7.2 Specimens under Test: Full length filler strips, 18 flat seals.

5.7.3 Experimental Set-Up: A full length flat sector of the support and seal system with 18 flat seals will be enclosed in a high pressure, three chamber test piece with provisions for electrical heating on the core side of the filler strips. The radial flow past the filler strips will be varied by adjustment of the relative pressures on both sides. The temperature gradients in the filler strips will be measured with thermocouples.

5.7.4 Test Parameters:

Inlet Pressure	1.0 to 700 psig
Inlet Temperature	140 to 500°R
Material Temperatures	Variable
Working Fluid	Hydrogen

5.7.5 Instrumentation and Data Acquisition

Pressures and pressure drops measured with Heise gauges and pressure transducers. Flow measurement with calibrated orifices. Temperature measurement with copper-constantan thermocouples.

5.8 Full Core Cold Flow Tests

5.8.1 Description: Consideration is being given to the possible use of the Phase I vibrations core as a full scale flow test vehicle. The core channels (fuel element and tie rod) will be plugged and the mass flow and pressure distributions will be determined for the core and lateral support system. Containers to serve as pressure vessels for these flow tests are required.

5.8.2 Specimens under Test: Complete core with support system.

5.8.3 Experimental Set-Up: Cold flow a plugged reactor at various pressure levels to determine the support system leakage and pressure distribution.

5.8.4 Test Parameters: Contingent on available pressure vessels.

5.8.5 Instrumentation: To be determined.

6. ANALYSIS AND DATA UTILIZATION:

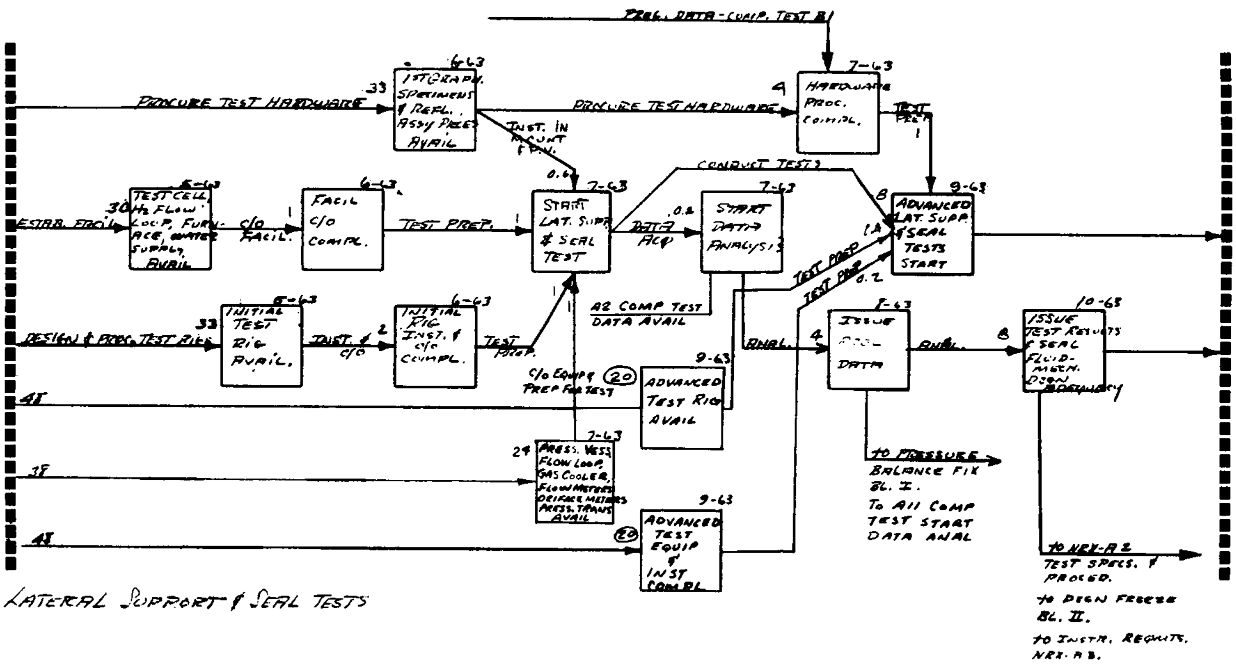
6.1 Using the data from the permeability studies, the design flow through the various parts of the support and seal system and the core periphery will be determined. Requirements for impregnation of the graphite will also be determined from this data.

6.2 The data from the isothermal single seal tests will be used to provide early information on the importance of various design parameters on seal leakage.

6.3 The data from the isothermal multiple seal tests will be analyzed to investigate the influence of multiple seal resistances and divers paths on the complete system leakage and pressure distributions.

6.4 From the information gained from the heated single seal tests, the effect on seal leakage performance due to distortion of the support and seal system and due to heat addition to the leakage paths will be determined. The test information will furnish sufficient data to determine the flow deviations produced by the distortions at each axial seal location and estimate the effect of heat addition over the entire length.

6.5 The full scale circular heated tests will provide proof of the validity of the combination of the results from the single seal and flat multiple seal tests, and will permit determination of the flow, thermal, and mechanical conditions that may exist due to off design operation and tolerance build-up.



B3 - LATERAL SUPPORT & SEAL TESTS

B3
4-8-63

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

B 4 GRAPHITE BARREL TEST

REVISION NO. 1

DATE: 3/30/63

1. TEST NUMBER: B 4

2. TITLE: GRAPHITE BARREL TEST

3. PURPOSE:

The evaluation of the design of the graphite barrel involves testing of the barrel under shock, vibration, and external pressure loads.

4. REQUIRED DESIGN DATA:

4.1 The leakage rate of hydrogen (at room temperature) through the graphite barrel will be determined. This permeability measurement will determine the order of magnitude of leakage that can be expected in operation and with the impregnated barrel.

4.2 The critical buckling pressure of the graphite barrel and the aluminum barrel under external pressure will be experimentally determined.

4.3 The axial and lateral resonant frequencies of the inner reflector are to be determined. The inner reflector with the hold-down spring assembly and the inner face seal assembly will be vibrated up to design vibration specifications and the internal damping of the graphite barrel will be determined.

4.4 Determine if inner reflector can withstand design shock specifications and confirm that the hold-down springs will keep the graphite barrel seated on the nozzle under ± axial and lateral shock loads.

4.5 Statistically evaluate the strength of the tapped threads in the graphite barrel. This involves numerous static and dynamic tests of internal graphite threads.

Engineer: Larry Parsons

Approved: [illegible]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

5. TEST PLAN:

5.1 Description of Tests

5.1.1 Permeability Test

Initially the permeability of the graphite barrel will be investigated. A network of hydrogen bottles with a flowmeter will be used to measure the permeability of the barrel. This test will be conducted without the aluminum barrel. A pressure differential of up to 100 psi will be exerted across section 5 of the barrel. The leakage rate will be obtained for various pressure differentials. Local overstressing or failure initiation in graphite can be detected by sound emission. The results will determine the order of magnitude of the leakage that can be expected through the impregnated graphite barrel in operation.

5.1.2 Buckling Test

The graphite barrel will be tested with a shrunk-on simulated 2219 aluminum barrel to simulate external support during operating conditions (i.e., to simulate cooling of the aluminum barrel). Nitrogen or air gas up to 200 psi will be exerted on the aluminum to buckle or fail the graphite barrel. Strain gages will be used to measure the tangential and longitudinal stresses and the effect of stress concentrations due to holes and discontinuities in the graphite barrel. The top and bottom ends of the barrel and pressure vessel will be sealed off such that an external pressure differential across the graphite barrel can be increased in steps of 10 psi. Radial deflections will be obtained along the length of the barrel as a function of the pressure load. Axial and radial restraints will be simulated. The axial compressive load in the graphite barrel can be obtained by tie bolts connecting the two flanges on the inside of the graphite barrel.

5.1.3 Vibration Test

The 5,000 lb. shaker will be used to shake the inner reflector at design axial and lateral loads. Stresses, deflections, and resonant frequencies of the inner reflector system will be determined. The internal damping characteristics of the barrel will also be determined. The vibration test will confirm whether the graphite barrel and inner face seal will remain seated against the nozzle plate under the design vibration specifications.

5.1.4 Shock Test

The inner reflector system will be shock tested in the sand-drop shock tester. The barrel will be subjected to axial and lateral design shock loads. The axial preload springs and inner reflector spring bearing ring will be used to hold the barrel in place in the same essential test rig as used in the vibration test.

5.1.5 Thread Strength Tests

Sections of the graphite barrel from the ends of over-sized unmachined barrels or from tested barrels, will be subjected to static dynamic tests to verify the lateral support thread design. A statistical distribution of the mechanical properties of the graphite threads will be obtained.

5.2 Components Under Test

For the buckling and leakage tests, an impregnated graphite barrel will be used. For the shock and vibration tests, prototype, interface seal assembly, spring bearing ring, spring restrainers, and a complete set of preload springs will be used.

5.3 Experimental Set-up

The graphite barrel is placed in a steel pressure vessel and the annular space is sealed and capped at both ends with aluminum rings.

In this buckling test, an aluminum barrel is shrunk on the graphite barrel. The annular space between the inner reflector and the outer pressure vessel is pressurized.

The same design of test rig used for the vibration test of the reactor (E 1) will be used for testing the inner reflector with hold-down spring assembly. This rigid, aluminum, barrel rig will also be used for axial and lateral shock tests on the inner reflector on the shock table.

5.4 Test Parameters

5.4.1 Leakage Test

Hydrogen Pressure 0 to 150 psi maximum room temperature.

5.4.2 Buckling Test

Nitrogen pressure 0 to 200 psi maximum room temperature.

5.4.3 Shock Test

Shock Loads - To design specification, axial and lateral.

5.4.4 Vibration Test

Steady static vibration - To design specification.

5.5 Instrumentation and Data Acquisition

The graphite barrel will be strain gaged for all tests. Pressure will be measured with gages. A loud speaker system will be used to detect sound emissions from the graphite barrel at cracking of graphite material. Radial deflection of the barrel under external pressure will be recorded with the aid of electrical transducers. A flowmeter will measure gas flow rate. An M.B. 5000 lb. shaker system with instrumentation will be used for the vibration test. The sand-drop shock table will be used for the shock test. Accelerometers will measure "G" loads.

6. ANALYSIS AND DATA UTILIZATION

6.1 Analysis of test data will be coordinated with the Analytical Section for verification of theoretical analysis of the inner reflector.

6.2 The test data will verify the present inner reflector design or demonstrate necessary design changes required for the inner reflector to meet expected design specifications.

6.2.1 Flow tests will determine whether present impregnation specification is satisfactory or if further impregnation is required.

6.2.2 Thread tests will statistically verify the graphite thread design used in conjunction with the lateral support springs.

6.2.3 The buckling adequacy of the complex perforated graphite barrel will be determined.

6.2.4 Tests will verify the analytical critical buckling pressure and mode of buckling.

6.2.5 Stress and deflection analysis for shock, vibration, and external pressure loads will be correlated.

6.2.6 Location and magnitude of various stress concentrations will be measured.

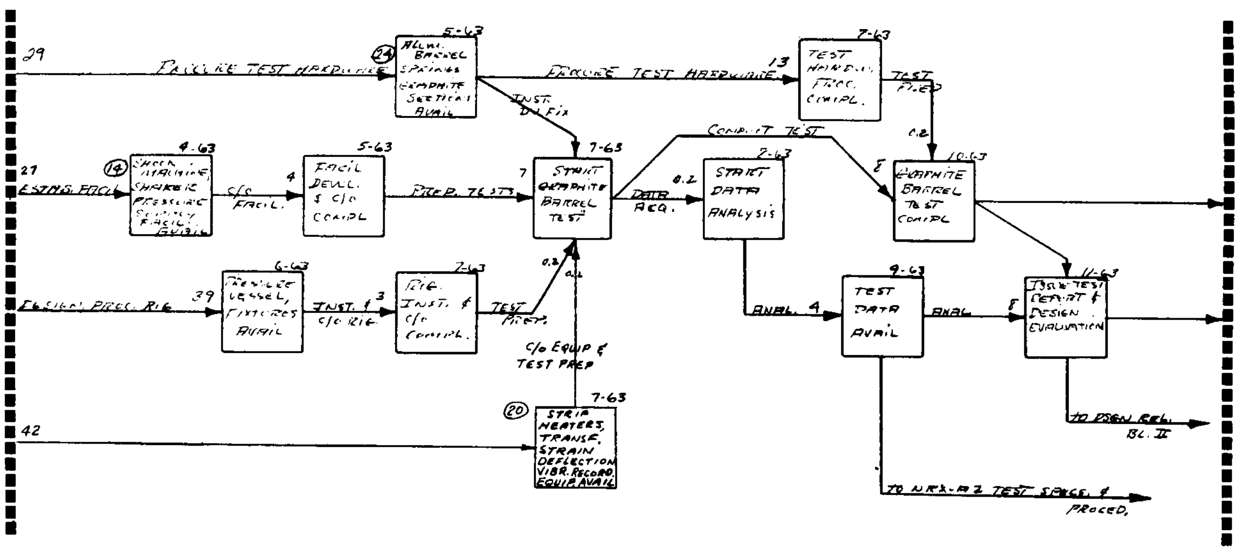
6.2.7 Tests will determine internal damping characteristics of the barrel to apply these results to analytical dynamic models of the reactor.

6.2.8 Fatigue resistance of the graphite barrel will be demonstrated by vibratory tests.

6.2.9 The adequacy of the inner face seal used in conjunction with the graphite barrel will be evaluated.

6.2.10 Axial shock and vibration tests will determine if the axial preload springs can hold the inner reflector in position on the nozzle seat under shock and vibration specifications.

Astronuclear



B 4 - GRAPHITE BARREL TEST

B 4
4-8-63

TEST SPECIFICATION

B 5 PARTIAL LENGTH CORE TEST

REVISION NO: 1

DATE: 3/30/63

1. TEST NUMBER: B 5

2. TITLE: PARTIAL LENGTH CORE TEST

3. PURPOSE:

The purpose of this series of tests is to evaluate the present and back-up designs of the lateral support sub-assembly under vibratory and shock loads. This includes not only structural evaluation, but experimental verification of the analytical calculations of the deflections, stresses, and resonant frequencies of the lateral support sub-assembly. The test will evaluate two laterial support designs, with a solid or fuel element core, under shock and vibratory loads.

4. REQUIRED DESIGN DATA:

4.1 Determine the displacements of the lateral support elements and the force distribution under shock and vibratory loads.

4.2 Obtain data on motion of the core and the modes of displacement of elements near mid-length position.

4.3 Determine the effect of lateral support pressure on core shape and damping during shock and vibration.

4.4 Evaluate wear on the lateral support elements and damage that is sustained by the components under shock and vibratory loading.

Engineer: Larry Parsons

Approved: [illegible]

5. TEST PLAN:

5.1 Description -- The lateral support components will be dynamically tested in a rig made to test a 9 inch length of the core. The rig will simulate the inner reflector and will contain the lateral support assembly. The core will be simulated by a 9" length solid graphite cylinder. Additional testing will be done with a core of 9" long fuel elements. The rig will be instrumented to obtain resonant frequencies, stresses, and deflections in the lateral support assembly. The vibration shaker will drive the rig laterally at various frequencies and at various "G" loads. The shock table will be used to laterally shock test the assembly. See Figure B 5-1.

5.2 Components Under Test -- The prototype components to be tested include those components of the lateral support system. In an alternate design this includes the lateral support block, the lateral support springs, and spring caps. In the present NRX-A design, this includes filler strip lengths, seal segments, plunger pin, and the lateral support springs.

5.3 Experimental Set-Up -- The test rig will be made of aluminum or graphite with holes corresponding to the number and location of holes in a 9" length of the inner reflector. (Each hole of aluminum barrel will have a graphite insert as a guide for the prototype lateral support system.) The entire assembly will be tested with a solid or fuel element type core. These are mounted on a granite slip table and vibrated over the frequencies and amplitudes indicated in the design specifications. Visual and transducer recordings will be made during the test.

Lateral shock tests will be made on the drop-test fixture. Both cores and lateral support designs will be tested.

5.4 Test Parameters:

5.4.1 Vibration Test

Frequency Range	-	5 - 2000 cps
"G" Load Range	-	0 - 5 "G"'s

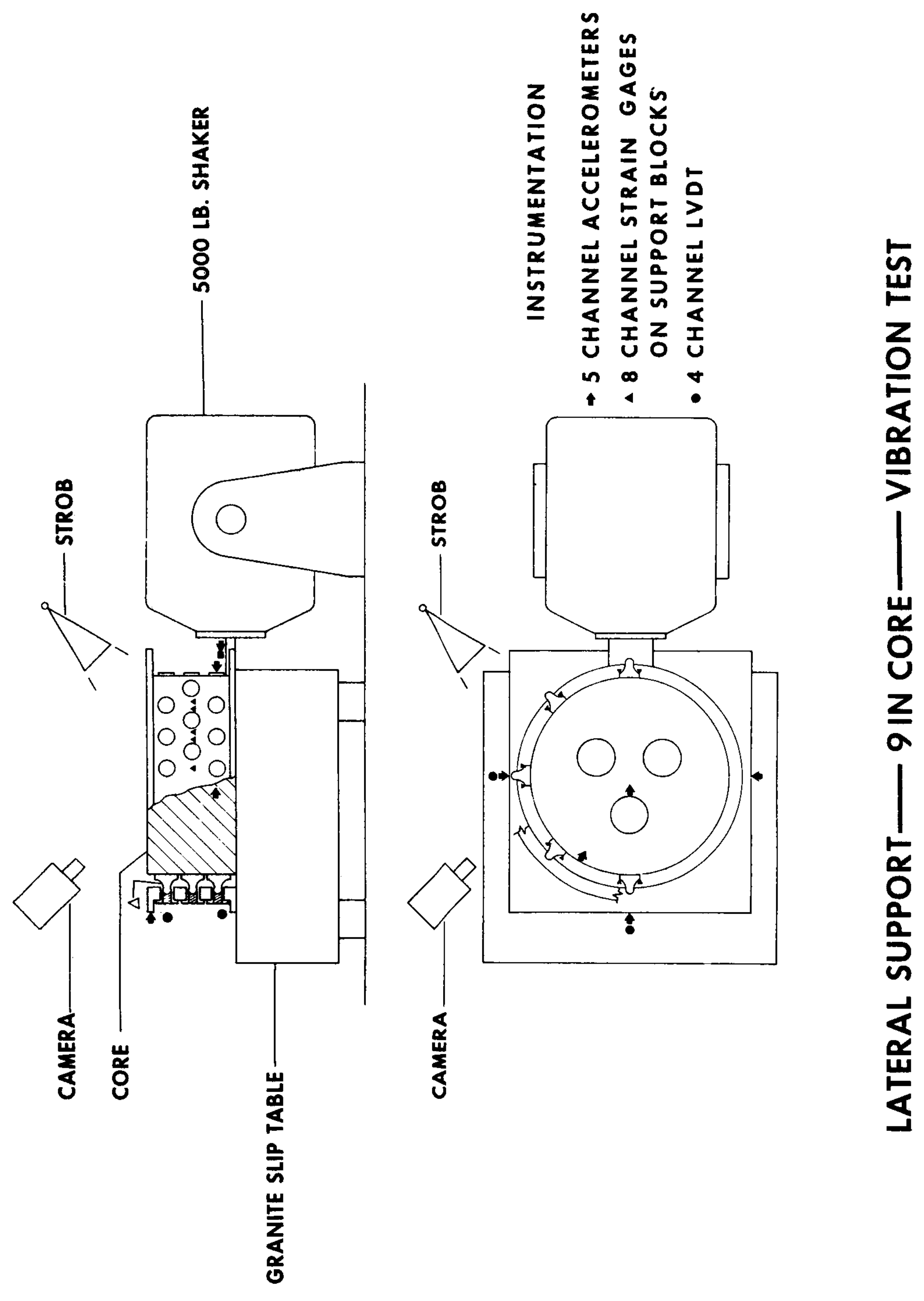


Figure B 5-1 Lateral Support -- 9 in. core -- Vibration Test

5.4.2 Shock Test

"G" Load Range	-	5 G
Time Duration	-	10 milliseconds

5.5 Instrumentation and Data Acquisition -- Data to be obtained includes the displacements of components, strains, frequency, "G" loads, and modes of motion. Instrumentation to be used to measure this data includes a high speed camera, strobotac, displacement transducers (LVDT's), strain gages and recording equipment. The 5000 lb. vibration shaker and instrumentation will be used for vibratory tests. The drop test fixture will be used for the various lateral shock tests of the assembly.

6. ANALYSIS AND DATA UTILIZATION:

The test results will be used to verify the calculations of the Analytical Section. The data obtained from the partial core length tests will be used to:

6.1 Verify the analytical model of the lateral support system load distribution and deflection.

6.2 Establish the repeating nature of the load distribution for a number of cycles and for deflections in various directions.

6.3 Determine the location of wear surfaces, the amount of debris created and the affect of this wear on seal surface, core periphery, and plunger clearances.

6.4 Verify the stresses in the lateral support blocks and seals under lateral loads.

6.5 Determine the effect of friction induced shear forces on the cement bond between the insulating tiles and filler strips.

6.6 Establish that the lateral support and seal assembly geometry will keep the insulating tiles against the core periphery under the various shock and vibration loads.

6.7 Establish the maximum amount of spacing required between the lateral support blocks at the core periphery of the alternate design. (This spacing directly affects radial and axial leak paths at the core.)

6.8 Determine the geometrical conformity between the lateral support and core periphery to determine the requirements for chamfers on the edges to prevent "catching" on filler strip irregularities.

6.9 Determine the geometry on the core under dynamic loading. (e.g., whether core elements separate.)

6.10 Verify adequacy of graphite thread design for spring retainer under the various loading distributions.

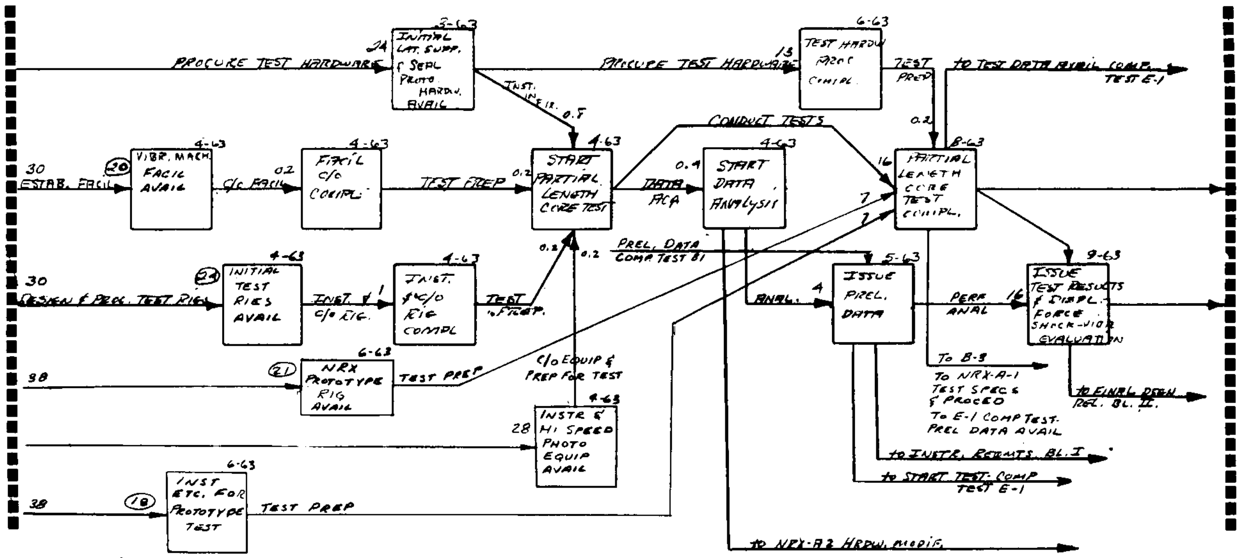
6.11 Determine the friction damping of elements versus a solid disc for the core under shock and vibration.

6.12 Determine the bundling ability of the lateral supports for various amounts of bow and twist the core elements.

6.13 Determine the eccentricity of the core with respect to the inner reflector after a shock and the influence of shocks applied to the eccentric core.

6.14 Determine the amount of cocking induced in the lateral supports under core deflection.

6.15 Determine break-away friction of lateral support.



B5 - PARTIAL LENGTH CORE TEST

B5
-1-8-63

TEST SPECIFICATION

C 1 IMPEDANCE RING FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: C 1 DATE: 3/30/63

2. TEST TITLE: IMPEDANCE RING FLOW TESTS

3. PURPOSE:

The impedance rings primarily limit the flow in the annuli between the inner and outer reflectors and between the outer reflector and the pressure vessel. This allows the flow in these paths to be balanced with the rest of the entire reflector system in such a way that problems of temperature distribution and mixing of non-isothermal hydrogen from the various paths are minimized.

The flow characteristics and loss coefficients of the impedance rings are required to balance the reflector flow for no maldistribution (ideal nominal design conditions), to predict the distribution through the steady state operation range of the reactor, to determine the effect of flow maldistribution in the annuli on the reflector components and the core as a result of deviations from nominal dimensions, and to define the flow distribution in the the reflector system during reactor transient operation.

Impedance ring flow characteristics must be studied in order that the proper geometry be selected to eliminate intolerable thermal gradients in the reflector and non-uniform temperature patterns which may be carried over to the core inlet in the NRX-A Hot Test.

Engineer: V. R. Amatangelo
Approved: E. A. De Zubay

4. REQUIRED DESIGN DATA:

4.1 Determine the pressure loss coefficient for the outer reflector-pressure vessel annulus impednace area.

4.2 Determine the effect of hole size, ring clearance and mis-alignment of mating flow surfaces on the pressure loss coefficient of the outer-reflector-pressure vessel annulus impedance area.

4.3 Determine the pressure loss coefficient for the inner reflector-outer reflector annulus impedance area.

4.4 Determine the effects of metering ring clearance, ring geometry and spacer geometry on the pressure loss coefficient of the inner reflector-outer reflector impedance area.

5. TEST PLAN:

5.1 Description -

5.1.1 A test fixture simulating the outer reflector pressure vessel annulus in shown in Figure C 1.1. The long rectangular flow passage simulates the annular flow clearance between the dome end support ring and the pressure vessel. This clearance and/or the converging area may be changed to study the effects of clearance and area ratio on the system pressure loss coefficients. The orifice plates above this annulus simulate the holes in the dome end support ring flange and in the supporting flange of the aluminum shield replacement. These holes may be varied in size and number to study their effect on the pressure loss coefficient. The shield replacement flange holes may be mis-aligned during assembly. This test fixture will provide for mis-alignment of 0 to $\pm$ 30 mils in 5 mils steps. The effect of this mis-alignment on the pressure loss coefficient will be

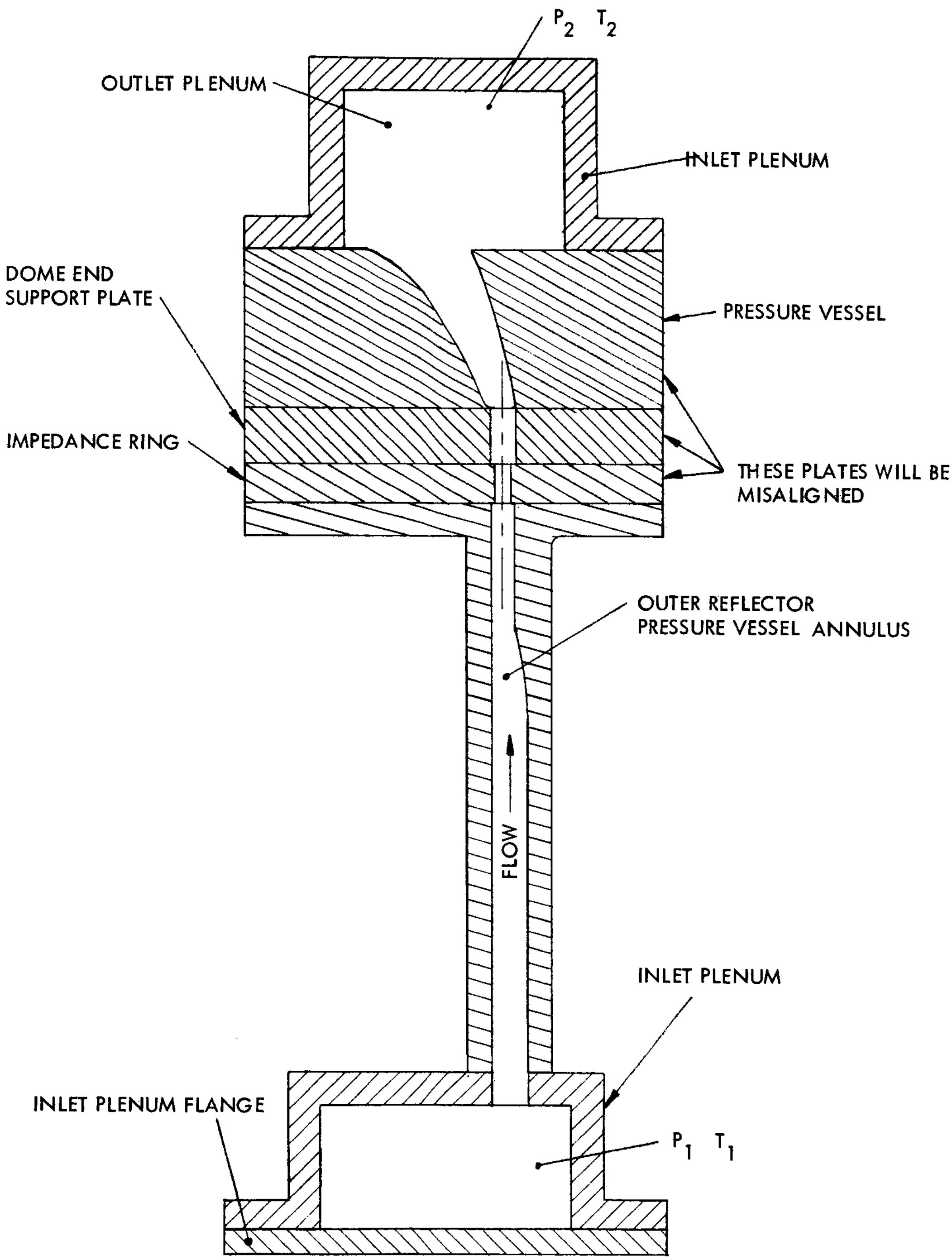


Figure C 1.1 Outer Reflector - Pressure Vessel Annulus Impedance Ring Model studied. The diverging area above these plates simulates the divergence flow path between the pressure vessel and the shield replacement dome end surface. This area may be varied and the effect of this area change on the pressure loss coefficient determined.

5.1.2 A test fixture simulating the inner reflector-outer reflector annulus is shown in Figure C 1.2. The long flow passage simulates the annular clearance between the aluminum barrel and the beryllium reflector. This clearance will be varied and its effect on the performance of the component studied. The vertical ribbed plate located at the center of this long flow passage simulates the spacer. The horizontal plate located near the entrance to the exhaust plenum simulates the metering ring. Both the spacer and the metering ring will be varied geometrically and the effect of these changes on pressure loss coefficient will be evaluated.

5.2 Component Under Test - The fixtures shown on Figures C 1.1 and C 1.2 will be the componentsunder test.

5.3 Experimental Setup

5.3.1 The models will be initially tested using the air supply and pressure gauges, thermocouples and manometers along with the test fixtures shown in Figures C 1.1 and C 1.2. The flow in both models enters inlet plenums, flows into the annuli, through the test sections and into the exhaust plenums.

5.3.2 Subsequent tests will be performed using hydrogen at ambient and liquid nitrogen temperature (140°R). Where necessary the model will be immersed in a dewar of liquid nitrogen to obtain an isothermal environment. Pressure gauges, thermocouples and differential pressure gauges will be used to measure test parameters.

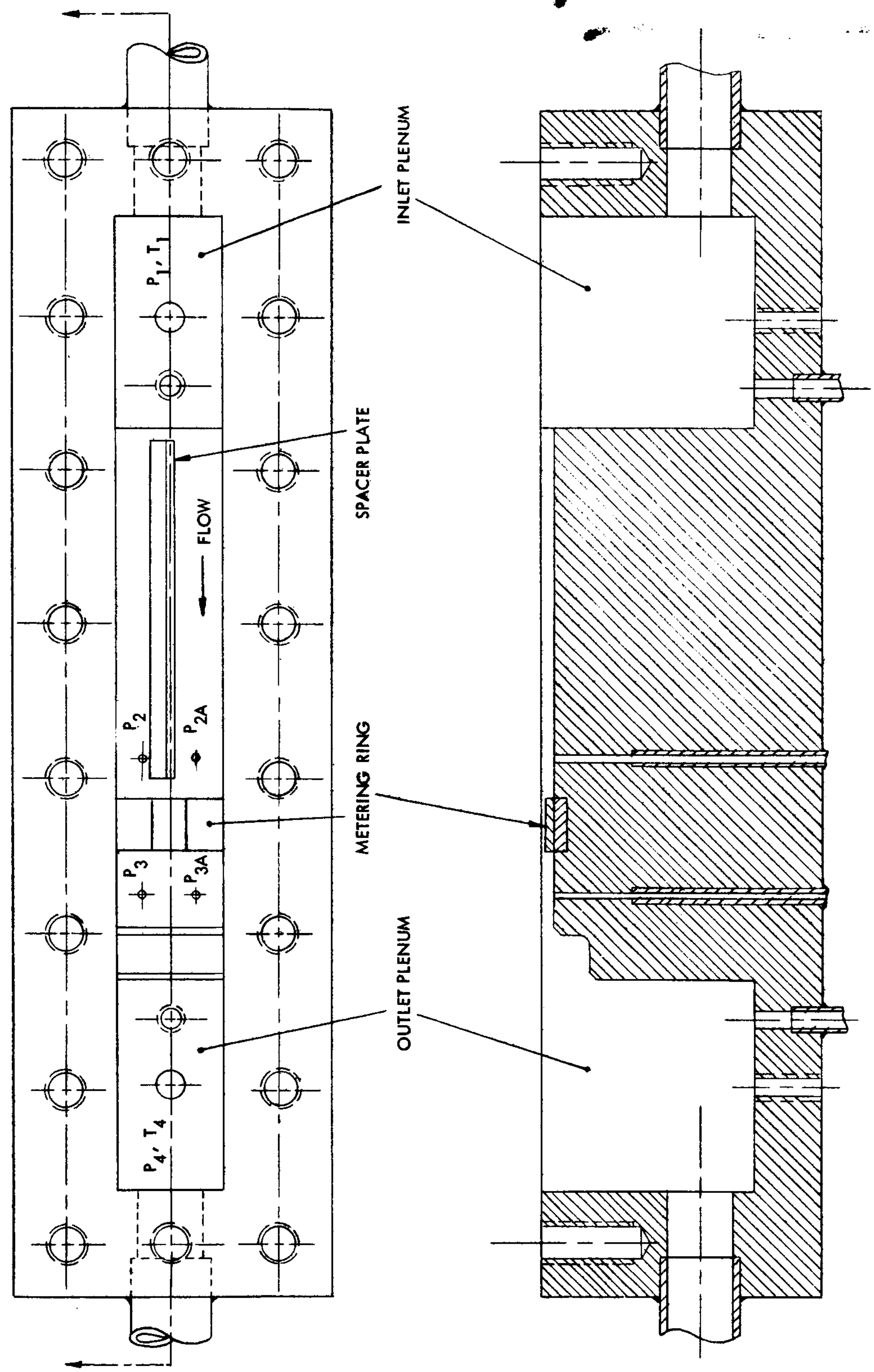


Figure C 1.2 Inner Reflector - Outer Reflector Annulus Impedance Ring Model

5.4 Test Parameters -

5.4.1 Outer reflector - pressure vessel annulus impedance area.

	AIR	HYDROGEN
Inlet Pressure	90 - 120 psig	300 - 730 psig
Inlet Temperature	530°R	140 - 530°R
Mass Flow	.39 - .88 pps	.10 - .2 pps
Pressure Drop	(Measured Variable)	(Measured Variable)
Flow Area and Geometry	(Variable)	(Variable)

5.4.2 Inner reflector - Outer reflector annulus impedance area.

	AIR	HYDROGEN
Inlet Pressure	90 - 120 psig	300 - 730 psig
Inlet Temperature	530°R	140 - 530°R
Mass Flow	.58 - 1.16 pps	.15 - .31 pps
Pressure Drop	(Measured Variable)	(Measured Variable)
Flow Area and Geometry	(Variable)	(Varibale)

5.5 Instrumentation and Data Acquisition - Tests will be made under equilibrium condition. Pressures and pressure drops will be read visually. Copper constantan thermocouples will be used in conjunction with a manually balanced potentiometer to measure temperature. A calibrated flow measuring nozzle will be used to measure the mass flow.

6. ANALYSIS AND DATA UTILIZATION:

Using the test parameters described in 5.4 the pressure loss coefficient C defined below, will be calculated. Correlation between C and Reynolds number, Re, will yield necessary pressure loss coefficients required to evaluate pressure flow balance and the effect of flow maldistribution in the reflector system.

$$C = \frac{2\ g\ \Delta P}{\rho\ V^2}$$

where

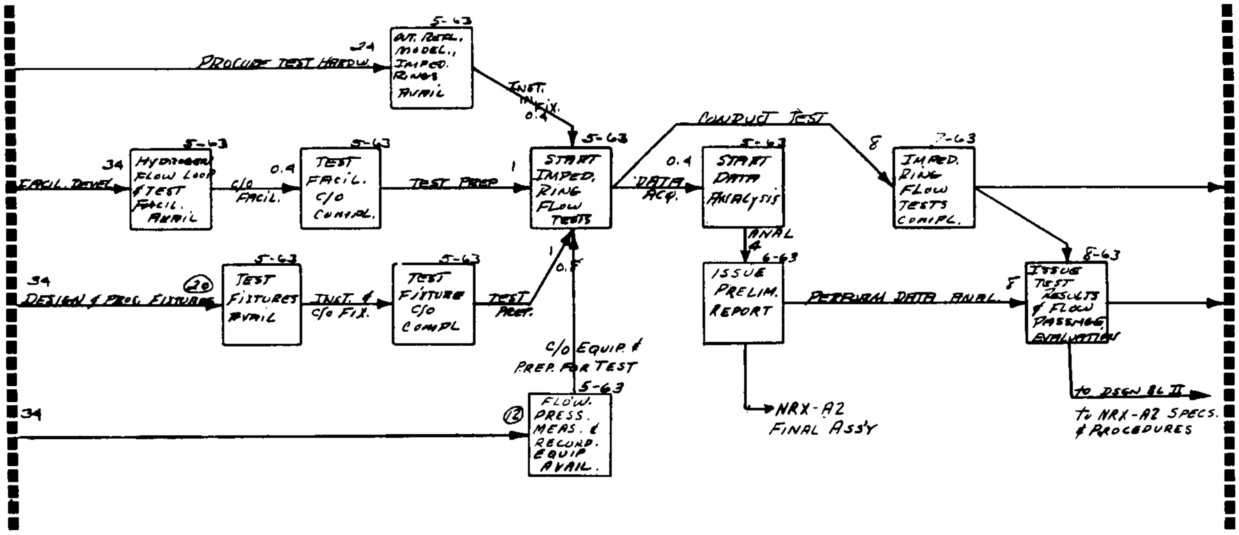
C = Pressure drop coefficient (dimensionless)

g = Gravitational constant (ft/sec^2)

ΔP = Static pressure drop across the component lbs/ft^2)

ρ = Density of the working fluid (lbs/ft^3)

V = Velocity of fluid in the component flow restriction (ft./sec.)



C 1 - IMPEDANCE RING FLOW TESTS

C1
4-8-63

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

C 2 SUPPORT SYSTEM MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: C 2 — DATE: 3/30/63
2. TITLE: SUPPORT SYSTEM MECHANICAL TESTS
3. PURPOSE:

The object of the tests on the support system of the NRX-A reactor is to verify the capability of the structure that transmits the core loads to the pressure vessel to withstand design inertia, pressure differential loads and temperature conditions without failure by rupture or excessive deflections.

4. REQUIRED DESIGN DATA:

4.1 Stresses of ligaments and of areas around the coolant holes of the core support plate for design loads at operating thermal environments.

4.2 Stresses in meridional and tangential direction, and around coolant holes, slots, and changes of section, in the support ring for design loads at operating temperature.

4.3 Stresses in dome end support ring for design loads and thermal environments at,

a) Flange connection to pressure vessel.

b) Portion of plate thinned in section for passage of drum.

c) Tie bolt penetrations.

d) Bearing housing connections.

e) Bolted connection with core support ring.

f) Joint between horizontal plate and vertical shell.

Engineer: Laurence P. Morgan

Approved: [illegible]

4.4 Stresses at tie bolt and control drum housing penetrations, on the nozzle end support ring, for design loads and thermal environment.

4.5 Stresses and deflections for design loads at operating temperature, and for thermal conditions of the following areas.

a) Interface between the core support plate and support ring.

b) Interface between support ring and support dome end outer reflector assembly.

c) Junction between support dome end outer reflector assembly ring and support dome end outer reflector assembly cylinder.

d) Interface between the support dome end outer reflector assembly and pressure vessel.

4.6 Deflection profiles of the core support plate for design loads and thermal conditions.

4.7 Deflections at control drum bearing supports, both dome and nozzle end, for design loads and operating temperature.

4.8 Deflections and deflection profiles of the core support plate for application of an annular load on the core support plate, to correlate with computer program.

4.9 Deflections and stresses in tie-bolts for design loads and thermal conditions.

4.10 Determination of the change in control drum torque as a function of axial load and thermal environment.

5. TEST PLAN:

5.1 Description (General)

a) Test Rig

The test fixture will consist of a basic unit that supports the test components on the perimeter of a simulated pressure vessel segment. The load path is provided from the pressure vessel segment through four stringbacks to the top support plate. An arrangement of hydraulic actuators separately applies the axial and lateral loads, and an insulated container for liquid nitrogen provides the means for maintaining environmental temperature.

b) Test

The static load test of the support system will be made separately for the forward, aft, and lateral design loads under ambient and environmental temperature conditions. The thermal gradient test will be made by heating one surface of the core support plate and cooling the rest of the assembly.

5.2 Components Under Test--The tests will be performed on the following main components.

a) Core Support Plate

b) Support Ring

c) Support, Dome End, Outer Reflector Assembly

e) Support, Nozzle End, Outer Reflector Assembly

f) Tie-Rods

Other hardware items that are required to complete the assembly for structural continuity will also be used. All the items will be true prototype equipment except the outer reflector segments.

5.3 Experimental Set-Up--In establishing the best location of strain gages the axial load test set-up, as indicated in Figure C2-1, will be used. Forward, and aft static loads will be applied at ambient temperature and the test components will be checked for stress patterns with stress coat and/or photostress techniques. The magnitude of the load to be

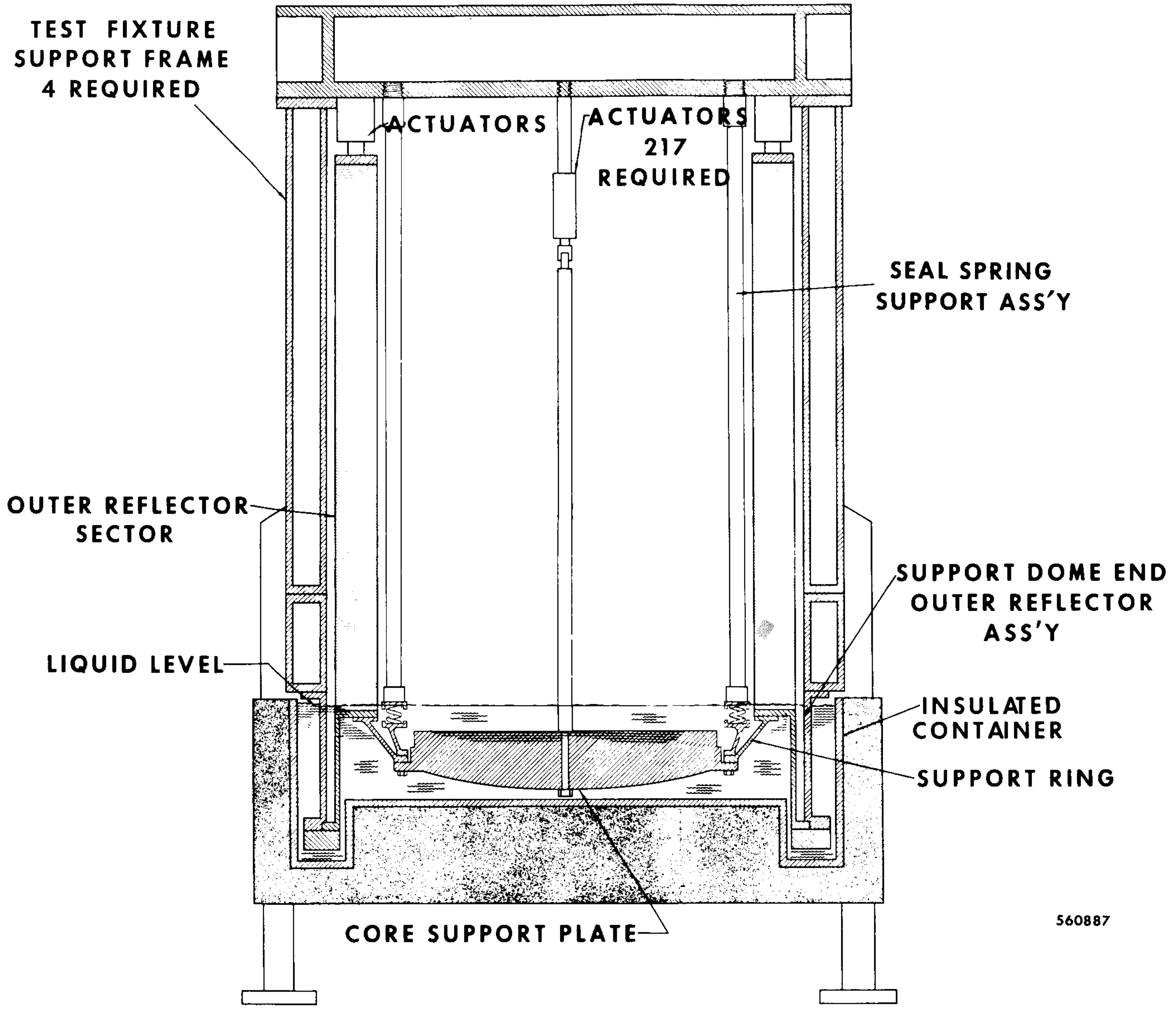


Figure C 2-1 Core Support Assembly Axial Load Test Rig applied will be large enough to give well defined stress patterns, but will not exceed 66% of the design loads. A sufficient number of strain gages will be used to monitor and establish the levels of the stress patterns.

After the stress patterns have been determined, the test components will be instrumented with strain gages and thermocouples to obtain maximum stress levels. These gages can be used as a check on the capability of the components. Also, instrumentation to obtain deflections of the core support plate, support ring, outer reflector, and control drum housing will be applied.

The first phase of load tests will be used to obtain influence coefficients for dynamic analysis. The hydraulic actuators are manifolded into four hexagonal groups oriented around the core centerline, and each group will be singly and simultaneously loaded incrementally to design values. Measurements of stresses and deflections will be made for each load.

Next the test components will be cooled by gaseous or liquid nitrogen and measurements of temperature, stresses, and deflections will be made. Then one cycle of aft design loads will be incrementally applied by hydraulic actuators attached at each regular tie rod location of the core support plate, and by the actuators at each outer reflector segment. Measurements of stresses and deflections will be made at each load increment.

In a similar manner as the aft load, a test of one cycle of forward loads will be made. Measurement of stresses and deflections will be made at each load increment.

The lateral load test will be made using the basic test fixture modified by a trunnion that supports horizontally mounted hydraulic actuators and a loading barrel sector that bears against the outer reflector (Ref. Figure C2-2). The instrumentation of the test components to obtain stresses

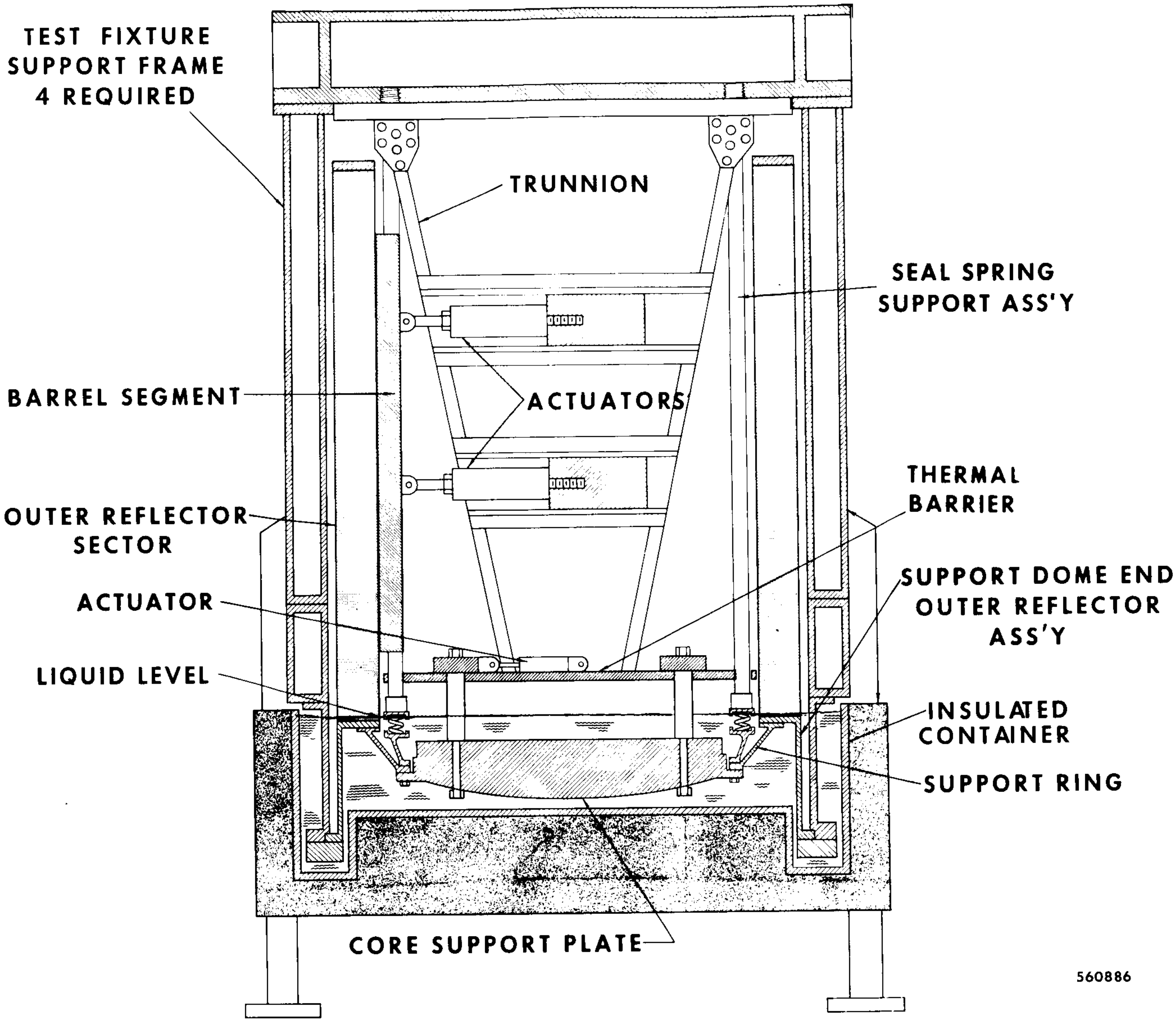


Figure C 2-2 Core Support Assembly Lateral Load Test Rig and deflections will be the same as in the forward and aft load tests with only modifications to meet specific details. In making the test, one cycle of lateral design loads will be incrementally applied under both ambient and environmental operating temperatures. Measurements will be made at each load increment. Also influence coefficients will be determined for lateral loading conditions by varying the load distribution to the core support plate and outer reflector sector. This test will be run at ambient temperature.

The thermal gradient test set-up will be as indicated in Figure C2-3. This test will be performed by heating one surface of the core support plate. and cooling the rest of the assembly with gaseous or liquid nitrogen. The temperature distribution that will be obtained will only simulate the operating gross effect. The instrumentation of the test components will be the same as in the load tests with modifications to meet specific details.

5.4 Test Parameters

Aft Inertia Factor	4.5 g at operating temperature
Aft Inertia Factor	8.0 g at ambient temperature
Forward Inertia Factor	1.2 g at operating temperature
Forward Inertia Factor	6.0 g at ambient temperature
Lateral Inertia Factor	4.0 g at operating temperature
Lateral Inertia Factor	4.0 g at ambient temperature
Pressure Differential (Across Core)	130 ± 20 psi.
Pressure Differential (Across Reflector)	35.7 ± 5 psi.
Temperature Differential	To be defined

5.5 Instrumentation and Data Acquisition--The strain measurements will be made with the use of foil or equivalent type strain gages. The readout equipment

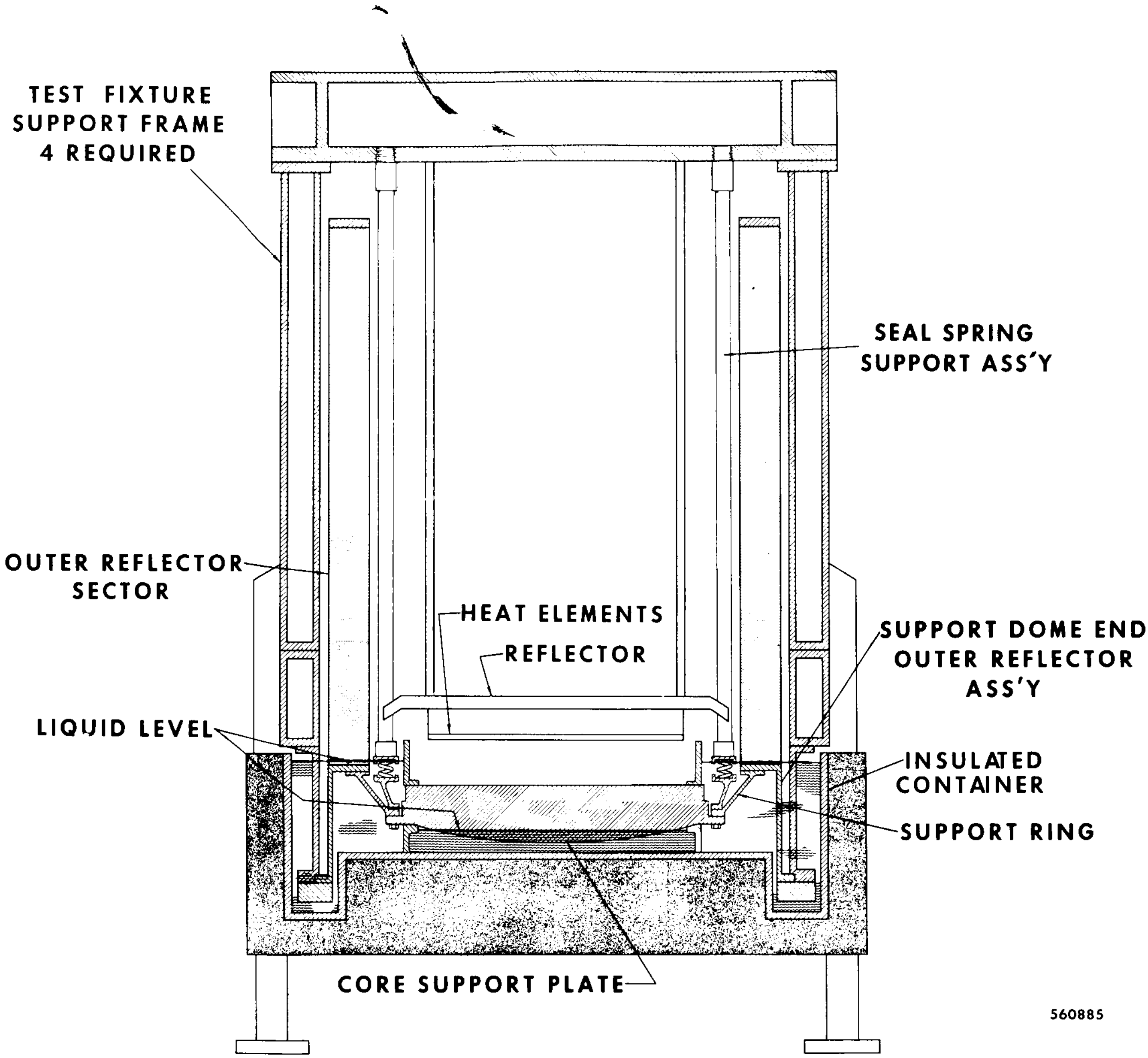


Figure C 2-3 Core Support Assembly Thermal Test Rig will be an automatic COHU switching unit with print out and a manual B.L.H. Type 20 strain indicator unit.

The temperatures measurements will be made with the use of copper-constantan thermocouples and readout using select channels of the COHU switching unit.

Deflection measurements will be made using dial indicators and optically by a precision cathetometer.

6. ANALYSIS AND DATA UTILIZATION:

6.1 The stress concentration factors due to the holes in the core support plate will be checked against published data. Also the magnitude of stress levels will be compared with permissible allowable stress values.

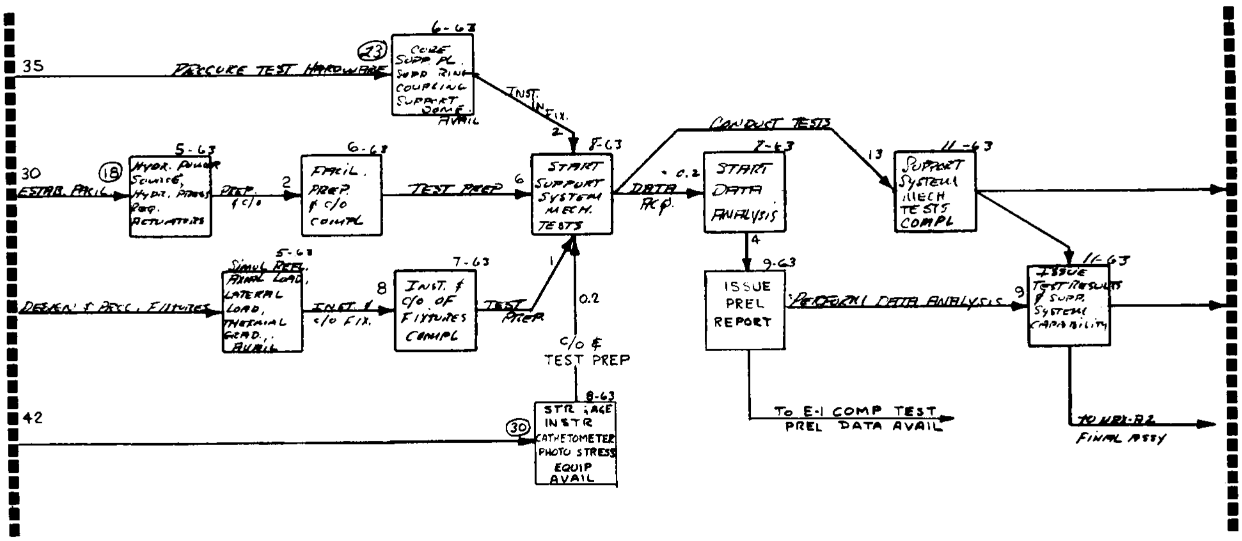
6.2 Support ring, support dome end outer reflector assembly, nozzle end support ring, and tie bolt stress levels will be compared with their respective allowables.

6.3 Interface stress and deflections will be compared with permissable allowances.

6.4 Deflection profiles of the core support plate will be evaluated from design considerations relative to core support.

6.5 Deflections of control drum housing will be evaluated with respect to the control drum operation, and the effect of torque levels.

6.6 Deflections and deflection profiles of core support plate for annular loads will be submitted for dynamic analysis.



C2 - SUPPORT SYSTEMS MECHANICAL TESTS

C2
4-8-63

TEST SPECIFICATION

D 1 REFLECTOR SEGMENT MECHANICAL TESTS

REVISION NO. 1
DATE 3/30/63

1. TEST NUMBER: D 1-1
2. TITLE: SURFACE GALLING TEST
3. PURPOSE:

There are three particular areas in the NRX-A engine where flat metallic surfaces are bolted together and are subjected to small amounts of sliding due to thermal expansions and contractions. Under NRX-A operating conditions of cryogenic and decay heating temperatures in hydrogen atmosphere, galling and cold metal welding may occur. This cold welding could prevent easy disassembly of the NRX-A engine for post-mortem inspection, and could prevent relative motions during operation and cause high stresses.

4. REQUIRED DESIGN DATA:

4.1 It is desired to check out the specific combinations of metals under laboratory conditions which simulate with sufficient accuracy the significant NRX-A operating conditions. Since serious galling or cold metal welding may occur, surface coatings will be evaluated in order to alleviate the condition.

5. TEST PLAN:

5.1 Description -

5.1.1 General Description of Test Rig -

The rig is a sliding contact cycling device. Two specimens are placed in contact and loaded against each

---

Engineer: A. N. Kallin
Approved: [signature]

other with a spring. An electric motor with an eccentric shaft and linkage is used to slide one of the specimens back and forth.

5.1.2 General Description of Test

Samples of various combinations of metals found in contact in the NRX-A engine are placed in the test rig. Pressure is applied between the pieces and a simulated atmosphere is used to enclose the specimens. A number of sliding cycles are applied and the specimens inspected for signs of galling or cold welding.

5.2 Components Under Test

Material test specimens 1/2" x 1/2" x 1/8" of the following materials: aluminum, beryllium, titanium. These specimens simulate the core support plate flange, the reflector upper surface, and the core dome end support ring flanges.

5.3 Experimental Set-up

Assemble a cycling test fixture with two flat specimens about 1/2 inch square in such a manner that relative motions of as much as .040 inch can be produced between the specimens while a contact pressure of 25,000 psi is simultaneously applied. Smaller motions may be used if they conservatively simulate galling conditions. The rig should be capable of measuring the frictional sliding force. A container of hydrogen gas at atmospheric pressure should surround the specimens.

5.4 Test Parameters

Temperature	-320°F to 500°F
Contact Pressure	25,000 psi
Motion per Cycle	Approximately .040"
Number of Cycles	30

5.5 Instrumentation and Data Acquisition

Cool the hydrogen gas to -320°F and apply 15 sliding cycles; stop the motion for one hour, and then apply 15 more cycles. Record the frictional force continuously.

Heat the gas to 500°F, instead of -320°F and repeat the above procedure.

Inspect the specimens for serious galling or cold welding.

Repeat the above procedure with two specimens of A110-AT titanium.

Repeat the above procedure with a combination of A110-AT titanium and hot pressed beryllium.

Repeat the above procedure with a combination of 2219 aluminum and hot pressed beryllium.

6. DATA UTILIZATION:

If serious galling has occurred in the testing and successful anti-galling coatings demonstrated, these coatings will be utilized on the NRX-A parts.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act 1954~~

Astronuclear
WANL-TNR-095

TEST SPECIFICATION

D 1 REFLECTOR SEGMENT MECHANICAL TESTS

REVISION NO: 1

DATE: 3/30/63

1. TEST NUMBER: D 1-2

2. TITLE: THREAD GALLING TEST

3. PURPOSE:

If galling or cold welding should occur, post-mortem disassembly would be delayed and expensive tapped components could be ruined, thereby, preventing their use in further test operations.

4. DESIGN DATA:

The objectives of this test are to define possible galling problems of the metallic threaded fasteners used in the NRX-A engine and to evaluate possible thread coating procedures to solve these problems.

4.1 To determine and define possible thread galling problems.

4.2 To evaluate and recommend thread coating procedures.

5. TEST PLAN:

5.1 Description--Bolts and nuts made of combinations of Titanium and various other materials will be torqued to known values against a calibrated spring. The assembled specimen will be cold and hot soaked; unbolting torques will be compared to bolting torques. The cycle is to be repeated fifteen times with visual inspection of the threads for signs of galling.

5.2 Components Under Test--Various combinations of nuts and bolts of Titanium and other NRX-A fastener materials.

Engineer: J. N. Kallin

Approved: M. Manjoine

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act 1954~~

5.3 Experimental Set-Up--A coil spring is used together with end plates to provide a constant load on the threaded fasteners. This coil spring rig can be put into an environmental chamber for soaking.

5.4 Test Parameters

Material Combinations

Bolt load	2500 lbs.
Temperatures	-320°F and 500°F
Atmosphere	Hydrogen at 1.0 psig.
Time	1 hr., 50 min. total
Torque	Assembly and disassembly values
Galling Damage	A result of testing
Surface Coatings	Various types to be determined

5.5 Data Acquisition--Calibrate the coil spring by loading it in compression in increments up to 2500 lbs. and measuring the deflection of each increment. This calibration should be done at room temperature. The resulting plot of load versus deflection should be linear and this will give the constant, "k" (lbs./in.).

Assemble the fixture using the titanium bolt and nut. Tighten the nut with a torque wrench and measure the deflection of the spring until a load of 2500 lbs. is reached, using the computed value of "k",(above). Record the amount of torque required.

Place the fixture in the low temperature pressure vessel and expose it to hydrogen gas at -360°F and 1.0 psig. for 30 minutes. Expose the fixture to hydrogen gas at 500°F and 1.0 psig. for 80 minutes.

Remove the fixture from the hydrogen and allow it to cool to room temperature.

Unscrew the nut with a torque wrench. Record the torque required. Inspect the threads of both the nut and bolt thoroughly for signs of galling. Take photos of significant galling damage.

Repeat the above procedure fourteen times or until significant galling damage is noted.

If any combinations produce significant galling damage, repeat the test on that combination using new specimens of the same items together with antigalling coatings.

6. DATA UTILIZATION:

Successful antigalling coatings will be used in the NRX-A engine.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act 1954~~

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

D 1 REFLECTOR SEGMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: : D 1-3 DATE: 3/30/63

2. TITLE: OUTER REFLECTOR TIE-BOLT PROOF TEST

3. PURPOSE:

The NRX-A Outer Reflector Tie-Bolts are stressed by thermal growths, inertia load and gas pressure. Fracture of these bolts would seriously impair reactor reliability; yielding could result in vibration and failure of associated parts. Knowledge of these bolts in meeting design requirements is required to evaluate their reliability.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine actual factor of safety.

4.2 Determine actual deflections under load at various environmental conditions.

5. TEST PLAN:

5.1 Description--The tie bolt is to be mounted in a tensile test machine. Various loads and environmental temperatures will be applied. Deflection measurements will be made using increasing and decreasing incremental loads. Loading and deflection measurements will be repeated if permanent set is indicated.

5.2 Components Under Test--Tie Bolt No. 944C405

5.3 Experimental Set-Up--The test apparatus will consist of a standard tensile testing machine. The tie bolt deflection along a 50" gage length will be measured at environmental temperature. Various enclosures and support

Engineer: J. N. Kallin

Approved: [illegible]

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

equipment will supply and maintain the required environmental conditions.

5.4 Test Parameters

Test	Load	Temperature	Environment
1	15,600 lb. max.	Room	Air Atmosphere
2	27,300 lb. max.	$150^{\circ}R$	Liquid Nitrogen
3	9,750 lb. max.	$500^{\circ}F$	Resistance Heaters, Air Atmosphere

5.5 Instrumentation and Data Acquisition--These tests will be made and data observed when the tie bolt reaches thermal equilibrium. Loads will be read visually on the readout device on the tensile test machine. Temperatures will be obtained by use of thermocouples.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Strengths measured will be compared with computed NRX-A tie bolt stresses. Measured thermal growths and stiffnesses will be compared with WANL Materials Handbook values.

TEST SPECIFICATION
D 1 REFLECTOR SEGMENT MECHANICAL TESTS

REVISION NO: 1

1. TEST NUMBER: D 1-4 DATE: 3-30-63

2. TITLE: BERYLLIUM REFLECTOR SPECIMEN THERMAL SHOCK TEST

3. PURPOSE:

The NRX-A outer reflector and control drum are made of solid blocks of beryllium. There are steady state and transient thermal stresses in these parts under normal operation due to the passage of cold hydrogen gas through drilled cooling holes. These stresses could cause cracking of the cold, brittle beryllium, and this cracking could jam a control drum, plug a cooling hole, or in the worst case, cause failure of the reactor support system of which the reflector sectors are a part.

4. REQUIRED DESIGN DATA:

The safety factor against cracking has been computed for the steady state case, and it is desired to prove this computation by failing a beryllium specimen under controlled conditions. A further objective is to determine the safety factor experimentally for normal start-up flow transients. The effect of longitudinal manufacturing scratches will also be evaluated.

Engineer: J. N. Kallin

Approved: [illegible]

5. TEST PLAN:

5.1 Description:

5.1.1 General Description of the Test Rig

The whole test rig consists of a bottled gaseous nitrogen supply, a heat exchanger, suitable piping and valving, and a holding fixture for the test specimen. A shield is built around the holding fixture to protect test personnel from possible flying fragments. Temperature and pressure instrumentation is attached to the specimen and holding fixture and wired to a 12 channel continuous recorder.

5.1.2 General Description of Test

The heat exchanger is filled to the capacity of the tubing with nitrogen under pressure. Liquid nitrogen is added to the container, cooling the tubing and high pressure gas to -320°F. The gas is ducted to the holding fixture where a latch type valve prevents flow. This latch is opened rapidly providing a step input of flow to the specimen. The flow is allowed to continue until the time period for the maximum thermal stress has elapsed. The recording equipment records the temperature profile obtained in the specimen. If the specimen does not crack, the pressure and flow are increased in subsequent test runs until the conditions just sufficient for cracking are obtained.

5.2 Components Under Test

The test specimens represent the section of the outer reflector and control drums where the thermal stress is greatest. They are cylinders of beryllium 1-1/2" long, and 1-3/8" in diameter, with a central axial hole simulating a cooling hole passage. A number of 0.060" holes are drilled to various radial depths to imbed thermocouples. Two of the six specimens have longitudinal scratches broached into the wall of the central hole.

5.3 Experimental Set-Up

Set up a heat exchanger for supplying nitrogen gas under a pressure of 1,000 psig at -320°F. To do this, form a coil of soft copper tubing of 5/8 OD at least 290 feet in length, so that it can be immersed in liquid nitrogen. The exit end of this coil should be at the bottom of the liquid nitrogen bath. In this way, smaller amounts of cold gas can be supplied by simply using a lower liquid level in the container.

Set up the heat exchanger and the test fixture (Dwg. No. 707 J 716) along with enough bottles of pressurized nitrogen gas to supply 1.50 lbs./sec. of gas to the inlet end of the heat exchanger at room temperature at 1,000 psig. Pressure regulators should be included so that lower pressures and flow rates can be used. A relatively quick closing valve (2 seconds) should be included at both the inlet and the exit of the heat exchanger. The valve at the exit of the heat exchanger should be capable of cryogenic operation. A shield of 0.060" metal should be built around the test fixture to protect personnel from possible flying fragments.

Insert Specimen No. 1 in the test fixture and precisely line up the flow passages with a wooden dowel or copper rod.

5.4 Test Parameters

Gas supply to specimen:

a) Pressure, 30 to 1,000 psig.

b) Temperature, about -320°F.

Specimen temperatures:

68°F to -320°F as functions of elapsed time.

Specimen condition:

Fractured, or unfractured (as a function of testing)

Specimen type:

Scratched, or unscratched.

5.5 Instrumentation and Data Acquisition

Insert tight fitting thermocouples (t/c's) in all the ten t/c holes in the specimen. Secure the t/c's so that intimate contact at the bottoms of the holes is assured. Connect the ten t/c's and an eleventh t/c connected to read specimen gas temperature to a continuous recording device of at least 12 channels. Install a pressure transducer in the tubing at the inlet to the rig. Connect this transducer to the 12th channel of the recorder.

Close the quick release latch and open both of the other valves. Set the supply tank regulators at 100 psig. Fill the heat exchanger with liquid nitrogen and allow the volume in the heat exchanger tubing to acquire a constant temperature. Start the recording equipment. Ensure that constant values are being measured for all readings. All temperatures should be near room temperature, including the t/c in the gas at the specimen.

Trip the release latch quickly. Allow the flow to continue for 15 seconds or until the rig inlet gas temperature rises sharply, indicating the depletion of the cold supply in the heat exchanger.

Close the other two valves rapidly.

Remove the specimen from the rig and examine it thoroughly for cracking. A borescope may be used as well as fluorescent penetrant inspection.

If no cracking has occurred, repeat the above procedure using a higher pressure. This pressure will be determined from the t/c readings. Lower flow periods will be adequate at these higher pressures.

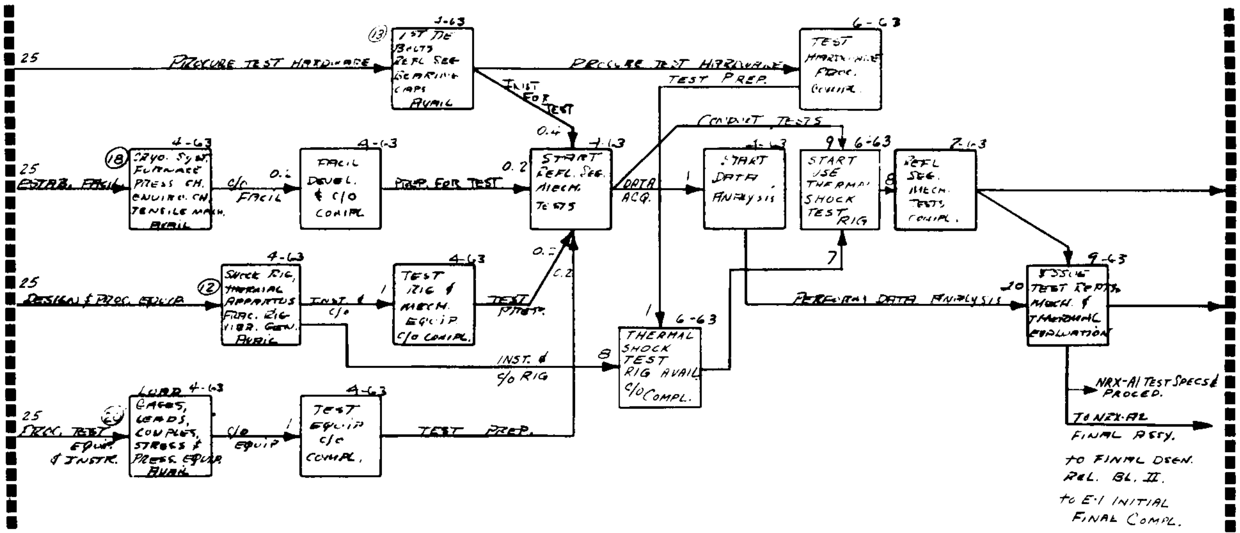
Reoeat the above procedure using the other specimens.

6. ANALYSIS AND DATA UTILIZATION

The testing will determine the thermal gradient which is just sufficient to cause cracking This gradient will be analyzed, using an IBM program, and the computed stress will be compared with steady state stresses previously computed for the NRX-A reflector to determine the actual safety factor for the part. The flow and temperature conditions of the test will be analyzed to determine if expected NRX-A start-up conditions could cause cracking, and if so, the NRX-A start-up will have to be made more slowly. The tests on the scratched parts will define the allowable size manufacturing scratches.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act 1954~~

Astronuclear



D 1 - Reflector Segment Mechanical Tests

DI
4-8-63

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act 1954~~

TEST SPECIFICATION

D 2 BERYLLIUM REFLECTOR ASSEMBLY FLOW TESTS

REVISION NO: 1

1. TEST NUMBER: D 2 DATE: 3/30/63

2. TITLE: BERYLLIUM REFLECTOR ASSEMBLY FLOW TESTS

3. PURPOSE:

The pressure drop characteristics through the beryllium reflector assembly must be established in order to assure the correct amount of flow through the section. Measurements of the flow impedance are necessary to avoid flow starvation, and consequently excessive reflector temperatures or temperature gradients and possible binding of the control drums. If the pressure drop is too small, other components such as the inner reflector may be operated at reduced flow and overheated. Correct flow passage sizing is necessary to operate the core at design conditions.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine the effect of the hole size and geometry on pressure loss coefficients for the dome end and nozzle end support rings.

4.2 Determine the effect of inlet and exhaust configuration on the pressure drop across the reflector.

4.3 Evaluate the pressure distribution and flow patterns in the thin plena between the support ring and the reflector.

Engineer: J. R. Bouille

Approved: E. A. DeZubay

5. TEST PLAN:

5.1 Description - A sector of the reflector assembly consists of a reflector, simulated by stainless steel tubes, inlet and outlet support rings, simulated by flat plates with flow holes, and the plenums between the support rings and the reflector simulated by spacer plates. The diameter of the holes in the inlet and exit support ring as well as the clearance between the support plates and the reflector are being varied. In addition to the above, various types of reflector inlet and exit configuration, i.e., sharp edged, rounded are being investigated.

5.2 Components Under Test - The components under test are the nozzle end support ring, a simulated reflector and the dome end support ring as shown in Figure D 2.1.

5.3 Experimental Set-Up - The test apparatus consists of the gas supply, reducing valve, heat exchanger for cooling the gas (where suitable), the test assembly, flow control valve, and the flow measuring orifice. Tests are being conducted using air at ambient temperature and 120 psig pressure and will be conducted using hydrogen at 200 to 700 psig and 140 to 530°R. The flow rates are being recorded as well as the pressure drops across the nozzle end support ring, the reflector inlet, reflector outlet and the dome end support ring. Tests are being performed for various flow hole sizes in the support rings and various geometries in the reflector inlet and outlet and the loss coefficients determined. Pressure distributions are being measured in the plena between the nozzle end support ring and the reflector and between the dome end support ring and the reflector. The effect of plenum volume on the pressure distribution is being examined.

5.4 Test Parameters -

	Air	Hydrogen
Inlet Pressure	120 psig	200 to 700 psig
Inlet Temperature	530°R	140°R to 530°R
Mass Flow	.025 to .55 pps	.005 to .11 pps
Pressure Drop	(Measured Variable)	(Measured Variable)
Geometry	(Variable)	(Variable)

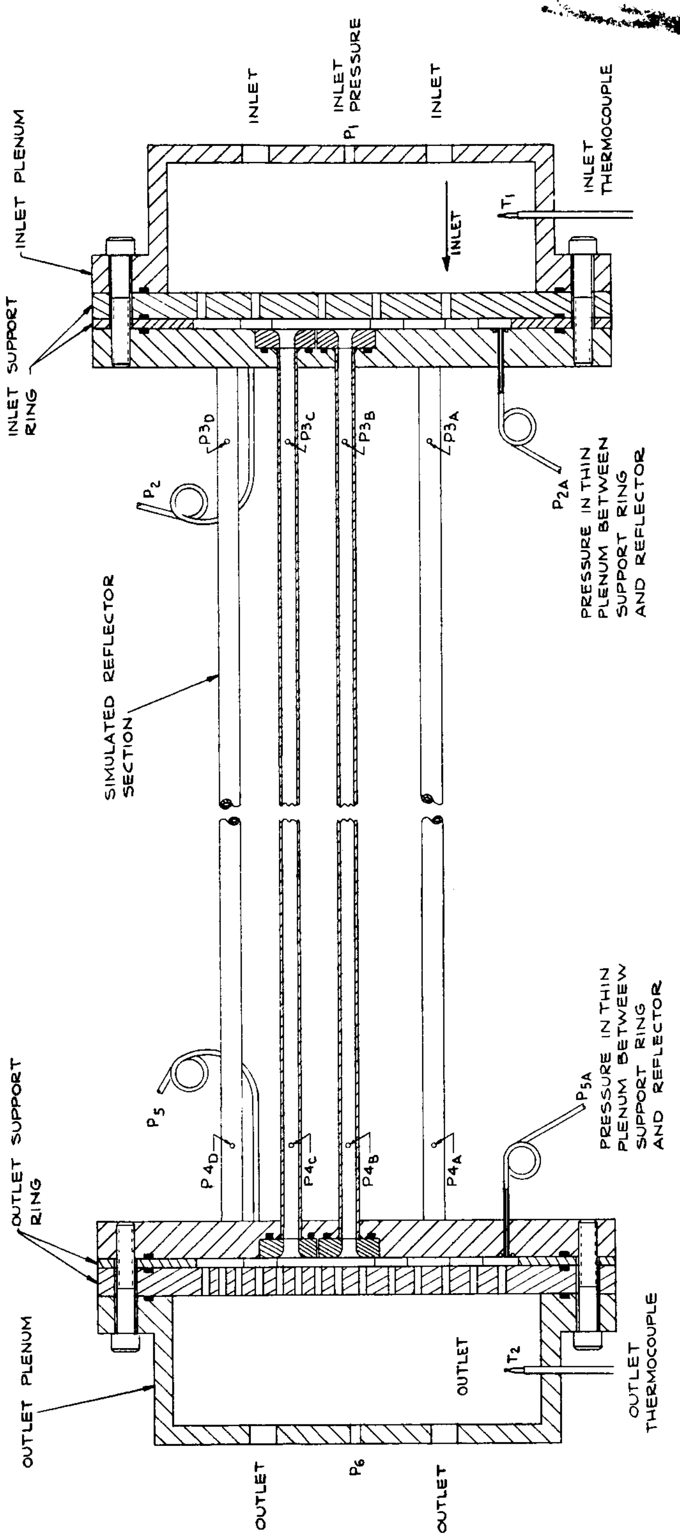


Figure D 2.1 Reflector Assembly Test Fixture

5.5 Instrumentation and Data Analysis - These tests are made under equilibrium conditions. For the air tests, the pressures are read visually by means of pressure gauges and the pressure drops by means of manometers. Copper constantan thermocouples are used to measure temperature on a manually balanced potentiometer. Flow is measured by means of an ASME calibrated flow nozzle. For the hydrogen tests the pressures are read visually by pressure gauges and the pressure drops on pressure differential gauges. Temperature is measured by means of thermocouples while the flow is measured by means of a sonic orifice.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Using measured flow passage sizes and the parameters described under 5.4, the loss coefficient (C) defined as:

$$C = \frac{2\,g\,(\Delta P)}{\rho\,V^2}$$

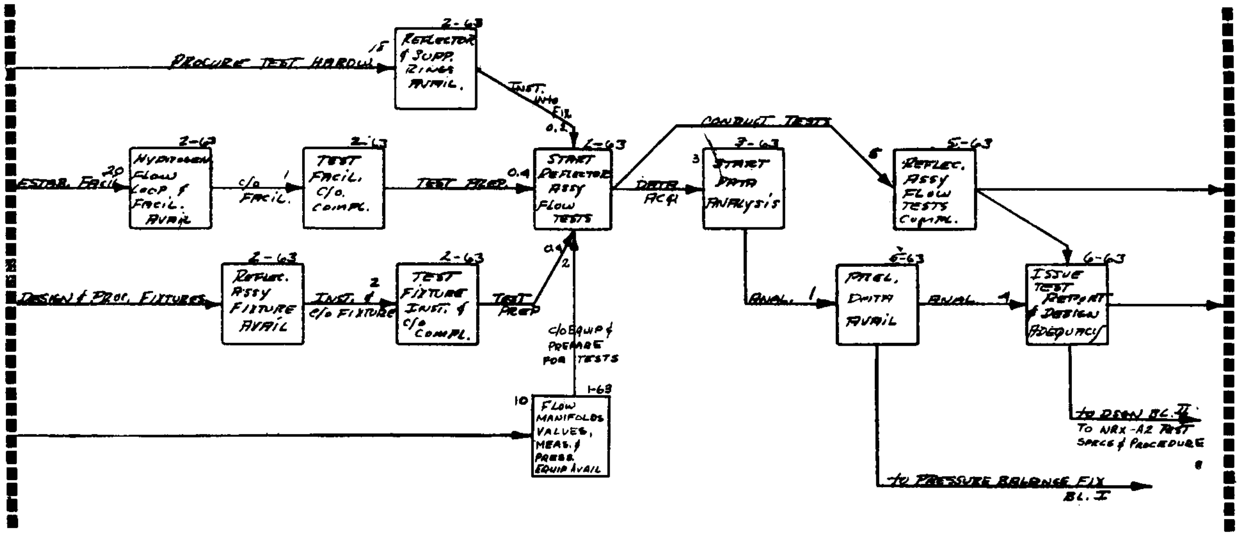
can be calculated where

C	=	pressure drop coefficient (dimensionless)
g	=	gravitational constant (ft/sec^2)
ΔP	=	static pressure drop across the component (lbs/ft^2)
ρ	=	density of the working fluid (lbs/ft^3)
V	=	velocity of hydrogen in the component flow restriction (ft/sec)

Correlations of the pressure loss coefficient with flow parameters and geometry must be established.

6.2 Data from the above tests will be used to determine or verify the sizes of the flow passages in the reflector support rings and the inlet and exit configuration for the beryllium reflector flow channels necessary to obtain the design flow and pressure drop.

Astronuclear



D2 - REFLECTOR ASSEMBLY FLOW TESTS

D2
4-8-63

CON[redacted]
RE[redacted]
At[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

D 3 CONTROL DRUM ASSEMBLY EVALUATION

REVISION NO: 1

1. TEST NUMBER: D 3

DATE: 3/30/63

2. TITLE: CONTROL DRUM ASSEMBLY EVALUATION

3. PURPOSE:

The purpose of the tests is to measure the control drum torque under simulated NRX-A operating conditions, and determine whether the control drum assembly and associated components can operate satisfactorily throughout the design life in the environments expected in the NRX-A tests.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Control drum torque under the various operating conditions.

4.2 Natural frequency of the drum assembly.

4.3 Drum vibration displacements and stresses resulting from mechanical excitation and gas flow through the annulus around the drum.

4.4 Pressure drop of the design flow though the annulus around the control drum.

5. TEST PLAN:

5.1 Description

a) General Description of Test Rig

The control drum assembly and associated components will be installed in a test chamber in which the cryogenic operating environment is reproduced, and subjected to shock, cycling and flow tests. Shock loadings will be obtained by striking the drum assembly with a pendulum.

Engineer: N. J. Bufano

Approved: [illegible]

[redacted]
Ato[redacted]

The drum will be rotated during the cycling and flow tests with a built-up laboratory actuator operating at room temperature. During the cycling and flow tests, the drum assembly will be vibrated with an electrodynamic shaker so that the effect of vibration on wear and operating torque can be evaluated.

Shakedown testing of the test equipment, shock tests in air, and cycling tests with nitrogen will be carried out in the Mechanical Testing Laboratory. Hydrogen testing will be performed in the Hydrogen Testing Facility.

b) General Description of Tests

The drum assembly will be subjected to the following tests.

1. Shock Tests

Mechanical shock loads will be applied transversely at the dome end support bearing and axially through the drum support barrel. Tests will be made in air and in nitrogen, or hydrogen, at cryogenic temperatures.

2. Cycling Tests

The drum assembly will be life cycled in nitrogen and hydrogen at cryogenic temperatures. Design vibration conditions will be simulated throughout the tests by means of an electrodynamic shaker. Excitation will be axial during half of the tests and transverse during the other half.

3. Flow Tests

Flow tests will be performed with gas flow at design conditions through the annulus around the control drum. These tests are intended to establish whether the flow will induce control drum vibration.

5.2 Components Under Test

a) Control Drum Assembly

b) Drum Support Bearings

c) Bearing Housings

d) Bias Spring

e) Drive Shaft

f) Drive Shaft Couplings

5.3 Experimental Set-Up

The test set-up consists of an environmental test chamber, a gas supply system, an electrodynamic shaker, and test stands required to support the chamber and shaker.

a) Environmental Test Chamber

The environmental test chamber, shown in Figure D3.1, consists of a barrel assembly in which the control drum is supported, a cryogenic test chamber, and a cover for the chamber to which may be attached either the NERVA control drum actuator or a laboratory actuator.

The barrel assembly consists of a titanium barrel (coefficient of expansion of titanium matches that of beryllium) simulating a reflector segment, a spring loading device for applying a thrust load on the dome end control drum bearing, bearing support end caps, and an extension cylinder required to obtain the proper separation between the control drum and actuator. The barrel assembly incorporates fittings which permit it to be vibrated axially and transversely. Electrical heating elements are mounted around the outside of the barrel to permit heating of the barrel and control drum to the maximum design temperature prior

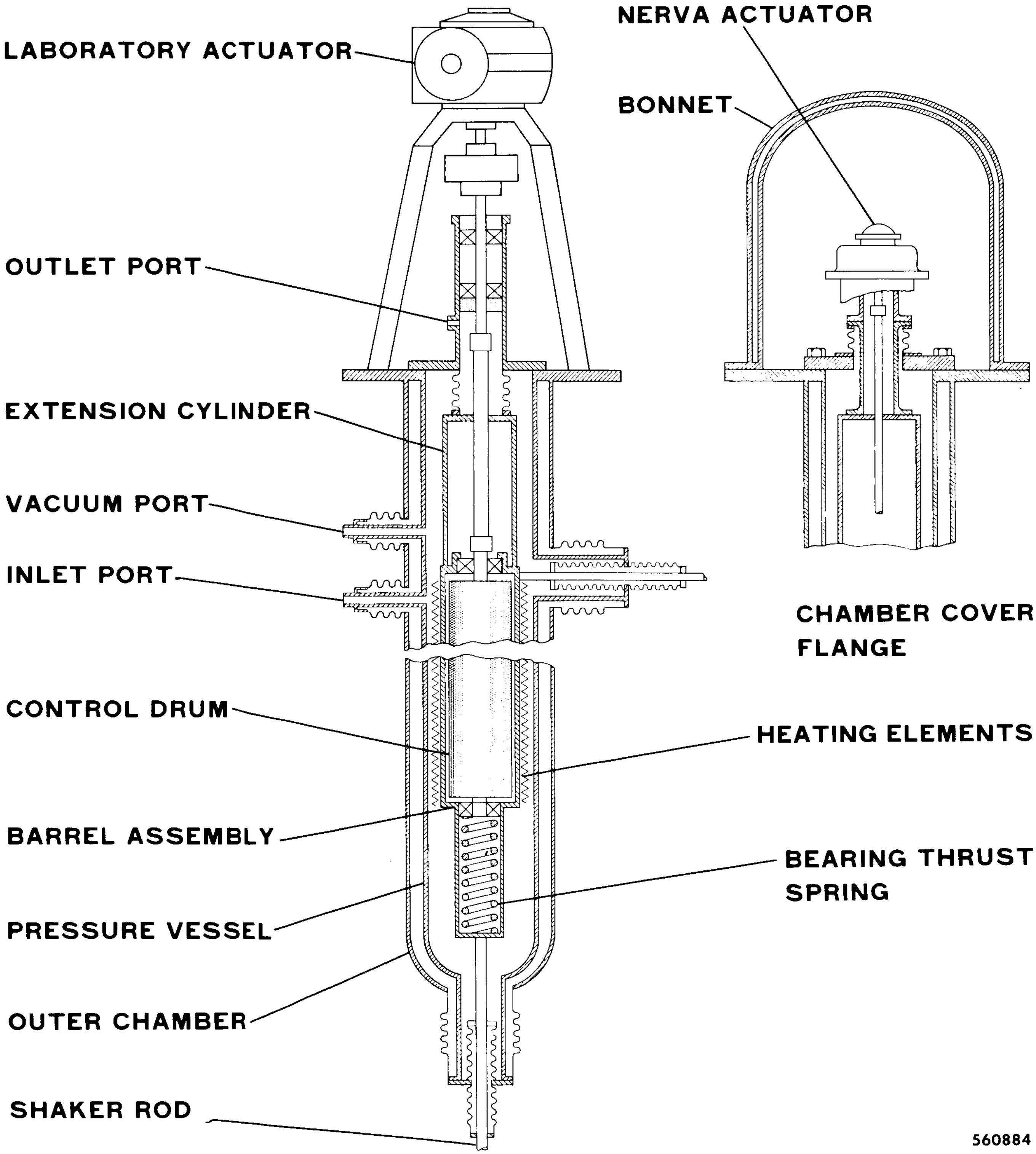


Figure D 3-1 Control Drum Environmental Test Chamber to the admission of liquid hydrogen or nitrogen into the test chamber. This provision was incorporated in order that transient tests may be performed to evaluate the control drum thermal distortion.

The cryogenic test chamber is a vacuum jacketed stainless steel pressure vessel which will permit the control drum and barrel assembly to be maintained at the high and low design temperatures. High temperatures will be obtained with electrical heating elements as described above, and low temperatures will be obtained by admitting liquid hydrogen or nitrogen into the chamber and permitting the flow rates required to obtain the desired temperatures. Thermal insulation will be applied on the external surfaces of the chamber cover flange and cover in order to minimize heat flow into the chamber.

For tests in which the laboratory actuator will be employed, the drum assembly is flexibly mounted in the cryogenic chamber through a bellows which is bolted to the inside surface of the cryogenic chamber cover. The actuator is attached to the outside surface of the cover and drives the control drum through the drive shaft. Self-aligning splines at the ends of the drive shaft permit the barrel assembly to be vibrated without restraint.

When it is desired to simultaneously test both the NERVA actuator and drum assembly under dynamic conditions, the barrel assembly is rigidly connected to the actuator, and the actuator is connected to the outside surface of the cryogenic chamber cover through an external bellows. In tests with the NERVA actuator it is possible to maintain design ambient conditions around the actuator by means of a vacuum jacketed bonnet which can be attached to the cryogenic chamber cover. High and low temperature environments will be obtained by electrical heating and cooling with cold hydrogen.

b) Gas Supply System

The gas supply system shown in Figure D3.2, consists of a control drum cooling system and a vacuum system. The cooling system is made up of gas bottles, an insulating tank with a cooling coil, and a pressure regulator. The insulated tank is filled with liquid nitrogen or hydrogen, and the gas from the bottle supply is chilled to approximately the temperature of the liquid gas in the tank by flowing through the tank cooling coils.

The vacuum system consists of a vacuum pump, a diffusion pump, and appropriate valving. This system is used to evacuate and purge the drum cooling loop, and also to maintain a vacuum around the pressure vessel and cold gas supply piping.

5.4 Test Parameters

Test	Test Medium	Inlet Gas Temp. °R	Inlet Gas Pressure psia.	Mass Flow lb./sec.
Shock	air	530	650	*
Shock	Nitrogen	150	650	*
Shock	Hydrogen	90	650	*
Cycling	Nitrogen	150	650	*
Cycling	Hydrogen	90	650	*
Flow	Hydrogen	90	650	0.3

*Sufficient to hold temperature rise in pressure vessel within 10°F.

[redacted]

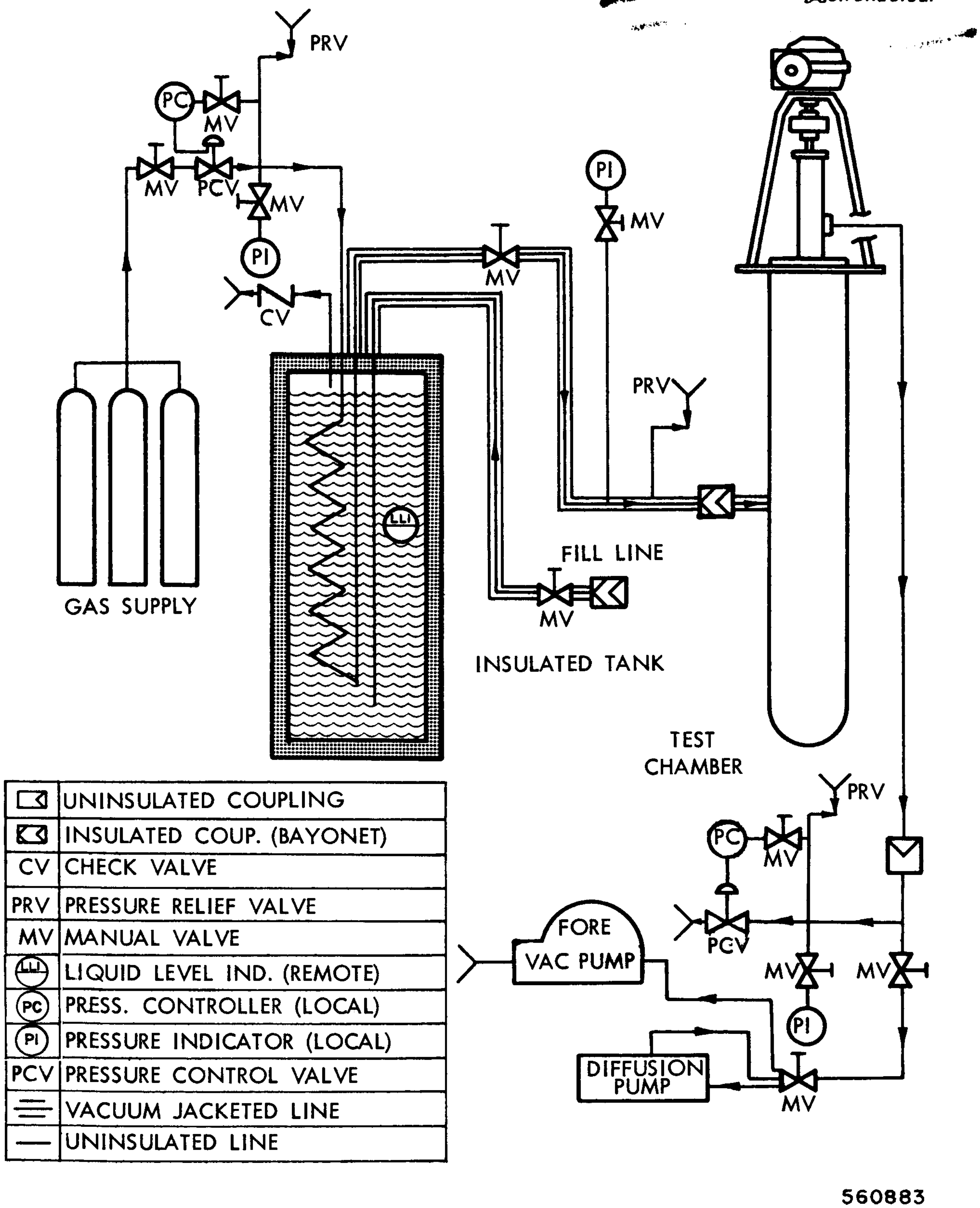


Figure D 3·2 Gas Supply System

5.5 Instrumentation and Data Acquisition

a) Control drum torque will be measured under the various operating conditions by inserting strain elements in the magnetic clutch which connects the actuator to the drum drive shaft.

b) The drum natural frequency and vibration stresses and displacements will be determined with strain gages and displacement transducers.

c) The mass flow and pressure drop through the annulus around the control drum will be determined by means of a flow meter in the inlet line and static pressure taps at each end of the drum assembly.

6. DATA UTILIZATION:

6.1 The data obtained from the control drum assembly tests will be used to:

a) Determine bearing wear, torque and resistance to shock.

b) Evaluate the durability of the control plate material and plate support system.

c) Determine whether flow through the annulus around the control drum will induce objectionable vibrations in the system.

d) Determine the ability of the control drum drive system to function properly in the design environments.

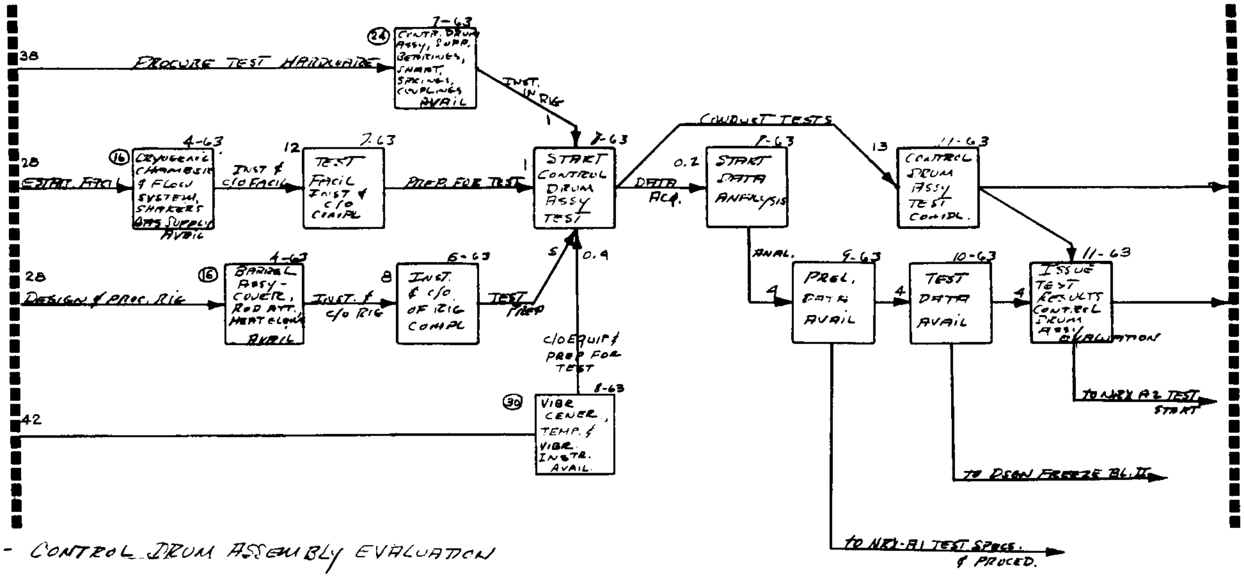
e) Determine whether differential expansion between components will cause problems such as galling and wear.

f) Evaluate fretting and wear of the crowned spline teeth on both ends of the drive shaft, particularly during conditions of misalignment between parts.

g) Determine the effect of drum bow due to the radial thermal gradient. The thermal gradient bow will be simulated by bowing the drum mechanically.

h) Determine stresses and deflections of the system components.

i) Determine the ability of the bias spring to keep the control drum against the stop under loads imposed by handling.



D 3 - CONTROL DRUM ASSEMBLY EVALUATION

D3
4-8-63

TEST SPECIFICATION

D 4 FLOW TESTS OF CONTROL DRUM SHAFT AND ORIFICES

REVISION NO: 1

1. TEST NUMBER: D 4-1 DATE: 3/30/63

2. TITLE: CONTROL DRUM - DRIVE SHAFT FLOW TESTS

3. PURPOSE:

Pressure loss coefficients are required along the control drum drive shaft coolant flow paths for design and off-design conditions. Flow distribution through the flexible couplings and exhaust holes of the drive shaft must be determined. Measurements of the loss coefficients and flow distribution are necessary so that the correct sizing of the drive shaft and nozzle end plenum inlet holes, nozzle end control drum plenum, and the other tortuous coolant passages can be achieved. This knowledge is necessary to insure a safe thermal environment for the control drum drive shaft innards during maximum power output of the NRX-A hot test.

4. REQUIRED DESIGN DATA:

4.1 Determine pressure loss coefficients for the control drum drive shaft flow passages.

4.2 Determine the control drum drive shaft pressure loss coefficients for variance in:

a) nozzle end control drum plenum inlet holes

2 hole sizes (.1875 inches and .2500 inches)

Engineer: J. R. Bonilla

Approved: E. A. De Zubay

b) nozzle end control drum plenum height changes (result from thermal expansion).

6 height changes up to .120 inches

c) drive shaft discharge holes

4 sizes ranging from .20 to .35 inches.

4.3 Determine flow leakage through the shaft flexible couplings.

5. TEST PLAN:

5.1 Description - The test model consists of a mock-up of the center two rings of control drum cooling holes in series with the control drum drive shaft. The flow passages are accurately machined so that the cross sectional geometry will duplicate the flow path (plenums and coolant holes) from the nozzle end of the control drum to the actuator end of the drive shaft. All cooling holes utilize tubing to simulate flow channels whenever possible. The mock-up is complete with control drum coil spring, flexible couplings, dome end bearing shaft, and nozzle end bearing shaft.

The flow enters the model at the nozzle end bearing shaft, a portion of the flow passes through a small variable plenum, then into the outer ring of eight (8) coolant holes. The other portion of flow passes through a large plenum containing a coil spring, from which it passes through an inner ring of four (4) coolant holes. The outer and inner ring of coolant flow converges at the dome end of the control drum and passes through the hollow dome end bearing shaft. Upon discharging from the dome end bearing shaft, some of the flow may leak out through flexible couplings into a large plenum. The remainder of the flow will exit through the drive shaft discharge holes and leak through the flexible coupling at the actuator end of the drive shaft.

The model will be tested first using ambient air and second using hydrogen. The tests will be run at varying pressures, temperatures, and flow rates, also for various drive shaft and nozzle end bearing shaft hole sizes, and nozzle end control drum plenum sizes. Drive shaft hole discharge flow will be measured and flexible coupling leakage will be determined.

5.2 Components Under Test - The component to be tested is a model composed principally of the two inner rings of coolant holes of the control drum and the drive shaft. To make the mock-up complete, these components are accompanied by their couplings, nuts, rings, and spacers.

In order to duplicate the control drum drive shaft, the model has been made in segments as shown in Figures D 4-1.1 and D 4-1.2.

5.3 Experimental Set-Up - The test apparatus consists of the gas supply, reducing valves, heat exchangers for cooling the gas (where suitable), filters, the test assembly, the flow control valve, and the measuring orifice. The test assembly is approximately one-half the actual length. All pressure readings are dual instrumented. There are 32 pressure readouts along the length of the test rig. The following locations are monitored along the test assembly:

5.3.1 Nozzle end bearing shaft inlet.

5.3.2 Control drum small variable plenum.

5.3.3 Large spring plenum at control drum inner ring inlet.

5.3.4 Control drum outer ring inlet.

5.3.5 Control drum inner ring inlet.

5.3.6 Control drum outer ring discharge.

5.3.7 Control drum inner ring discharge.

5.3.8 Outer and inner ring converging passage.

5.3.9 Dome end bearing shaft discharge.

5.3.10 Inner couplings.

5.3.11 Upstream of drive shaft discharge holes.

5.3.12 Downstream of drive shaft discharge holes.

5.3.13 Discharge plenum.

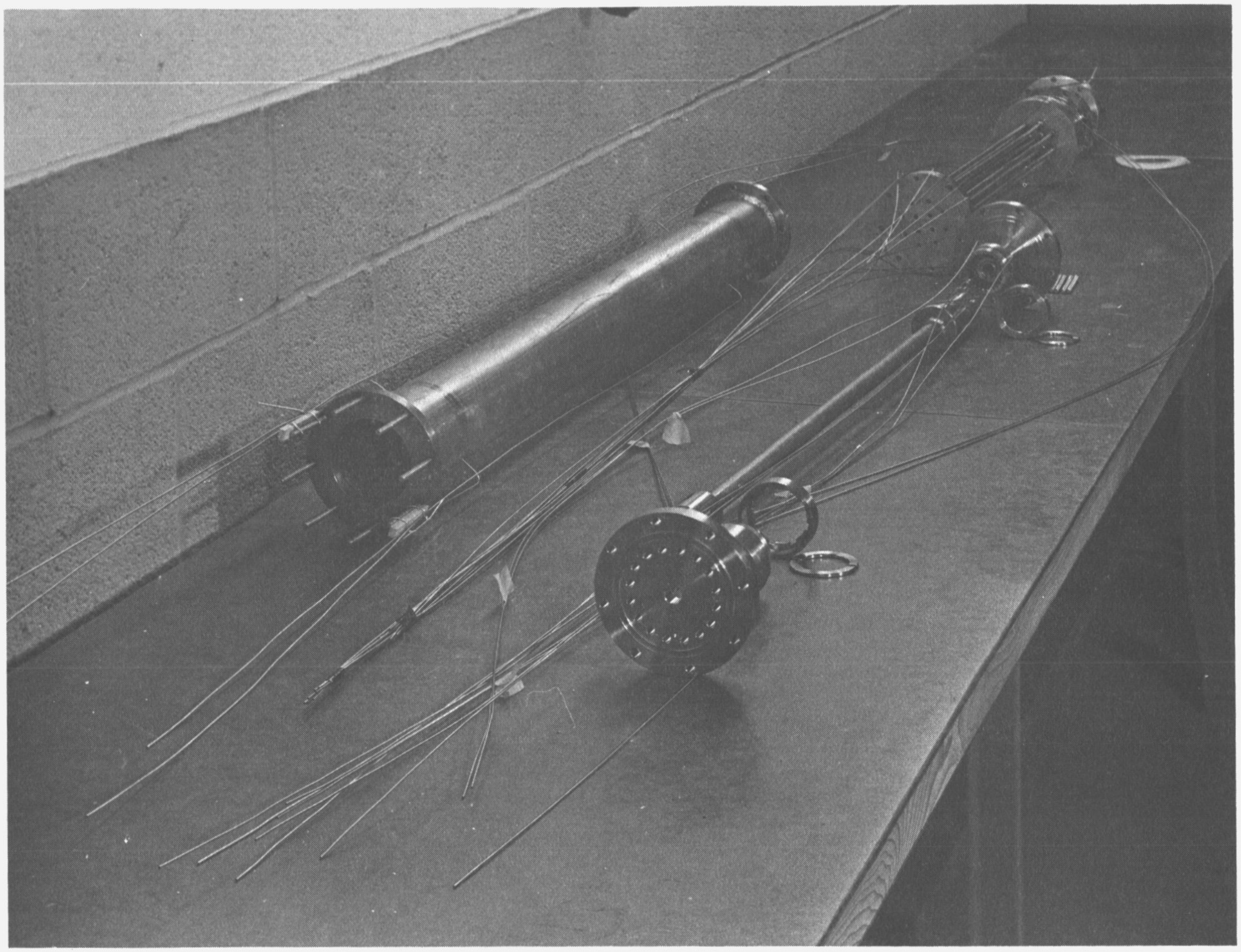


Figure D 4-1. 1 Control Drum-Drive Shaft Assembly - Discharge Side

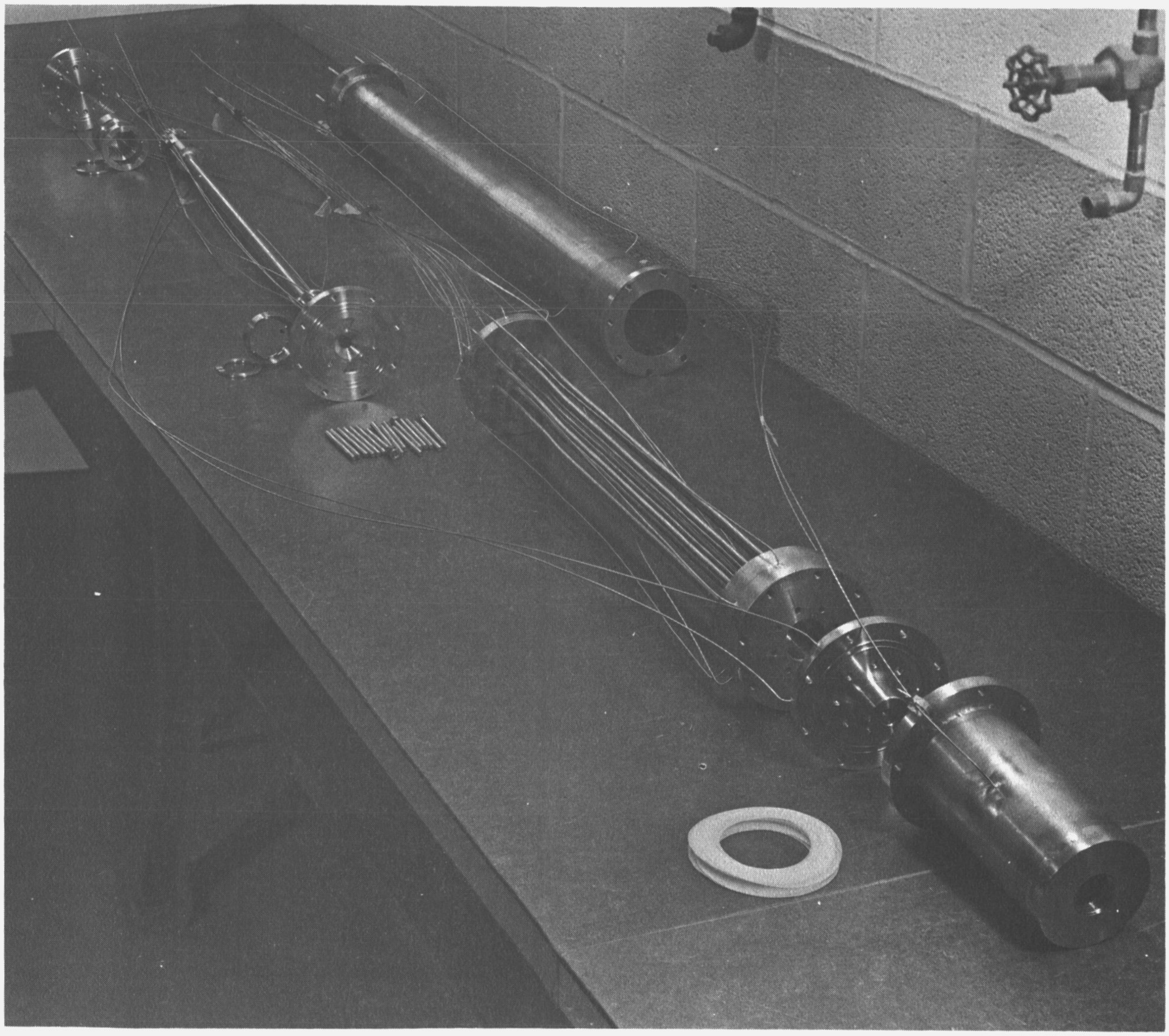


Figure D 4-1. 2 Control Drum-Drive Shaft Assembly - Inlet Side

Ambient air flow test temperatures will be measured with chromel-alumel thermocouples while for the cryogenic hydrogen tests, copper constantan thermocouples will be used. For the hydrogen flow tests, the entire test section will be submerged in liquid nitrogen contained within an 82 inch dewar. The submersion in the dewar will produce an isothermal condition of operation.

5.4 Test Parameters -

	Air	Hydrogen
Inlet Pressure	120 psig	300 - 660 psig
Inlet Temperature	530°R	140 - 530°R
Mass Flow	.8 - 1.6	.15 to .31 lb/sec.
Pressure Drop	(Measured Variable)	(Measured Variable)

5.5 Instrumentation and Data Acquisition - These tests are made under equilibrium conditions. Pressures and pressure drops are read visually. Precision Heise gages are used for pressure measurement. U-tube mercury manometers are used for pressure drop measurement. Copper constantan thermocouples (hydrogen tests) and chromel-alumel thermocouples (air tests) are used to measure temperature on a manually balanced potentiometer. The standard for measuring the flow is a sonic orifice (hydrogen tests). A flow nozzle is used for measuring the flow during the air tests.

6. ANALYSIS AND DATA UTILIZATION:

Using scale measured parameters (hole sizes) and those test parameters described under 5.4, the loss coefficient (C) defined as:

$$C = \frac{2\,g\,(\Delta P)}{\rho V^2}$$

can be calculated where:

- C = pressure drop coefficient (dimensionless)
- g = gravitational constant (ft/sec^2)
- ΔP = static pressure drop across the component (lbs/ft^2)
- ρ = density of the working fluid (lbs/ft^3)
- V = velocity of hydrogen in the component flow restriction (ft/sec)

Correlations of the pressure coefficient with flow parameters and geometry must be established. These data will be used to establish design flow areas for proper cooling of the components within the control drum assembly; to determine leakage rates; flexible shaft characteristics; and the effects of varying drive shaft and nozzle bearing shaft hole size; and the effects of nozzle end plenum height.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

Astronuclear

TEST SPECIFICATION

D 4 FLOW TESTS OF CONTROL DRUM SHAFT AND ORIFICES

REVISION NO: 1

1. TEST NUMBER: D 4-2 DATE: 3/30/63

2. TITLE: MEASUREMENT OF LOSS COEFFICIENT OF THE CONTROL DRUM FLOW CONTROL ORIFICES

3. PURPOSE:

Orifices are required to control the flow through the control vane cooling channels and the outer ring of drum cooling holes. The pressure drop for these orifices which govern the flow through the control vane cooling channels and the drum cooling holes must be established in order to assure the correct amount of flow through these sections. Correct flow passage sizing is necessary to operate the core at design conditions and insure the integrity and reliability of the NRX-A hot test.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Determine the pressure loss coefficients for the nozzle end bearing shaft plate, bearings, bearing housings and dome end bearing shaft.

4.2 Determine the flow distribution in the control vane cooling channels and the drum cooling holes.

5. TEST PLAN:

5.1 Description - A complete full size aluminum and stainless steel drum assembly will be used in a simulated pressure vessel designed initially for air test but

---

Engineer: D. R. Bouille

Approved: E. A. DeZubay

[redacted]

suitable for a full scale hydrogen test. Complete working conditions will be duplicated and the drum will be rotated to various positions in the test pressure vessel.

5.2 Components Under Test - The components under test are the nozzle end bearing shaft, bearings, bearing housings and dome end bearing shaft.

5.3 Experimental Set-Up - The test apparatus consists of the gas supply, reducing valve, heat exchanger for cooling the gas (where suitable), the test assembly, flow control valve, and the flow measuring orifice. The test fluid passes from a plenum through the nozzle end bearing cap and through the bearing itself into a small plenum. Individual mass flow rates and pressure drops across these components will be measured. From this small plenum, the flow proceeds through the nozzle end shaft plate and up into the outer row of cooling holes and cooling vanes in the control drum. The size of the flow holes in the nozzle end bearing cap and in the nozzle end shaft plate will be varied and the effect of this variation on pressure drop will be determined. After passing through the control drum the flow exhausts through the dome end shaft plate, which has a series of metering holes in it. After passing through this shaft plate, part of the flow must pass out through the dome end bearing cap and the rest proceeds on through the bearing to the exit plenum, impinging on the on the safety spring. As before, the size of these flow holes will be varied and the individual mass flow rates and pressure drops across the components will be noted. Tests will be conducted using air at ambient temperature and 120 psig pressure and will be conducted using hydrogen.

5.4 Test Parameters -

	Air	Hydrogen
Inlet Pressure	90 psig	400 - 700 psig
Inlet Temperature	530°R	140 - 530°R
Mass Flow	4 - 8 pps	0.83 - 1.66 pps
Pressure Drop	(Measured Variable)	(Measured Variable)
Geometry	(Variable)	(Variable)

5.5 Instrumentation and Data Analysis - These tests are made under equilibrium conditions. Pressures are read visually by means of pressure gauges and the pressure drops by means of manometers. Copper constantan thermocouples are used to measure temperature. Total flow will be measured by means of an ASME calibrated nozzle while individual flows with the assembly will be measured by calibration of individual components or helium tracer techniques.

6. ANALYSIS AND DATA UTILIZATION:

6.1 Using measured flow passage sizes and the parameters described under 5.4, the loss coefficient (C) defined as:

$$C = \frac{2\,g\,(\Delta P)}{\rho V^2}$$

can be calculated where:

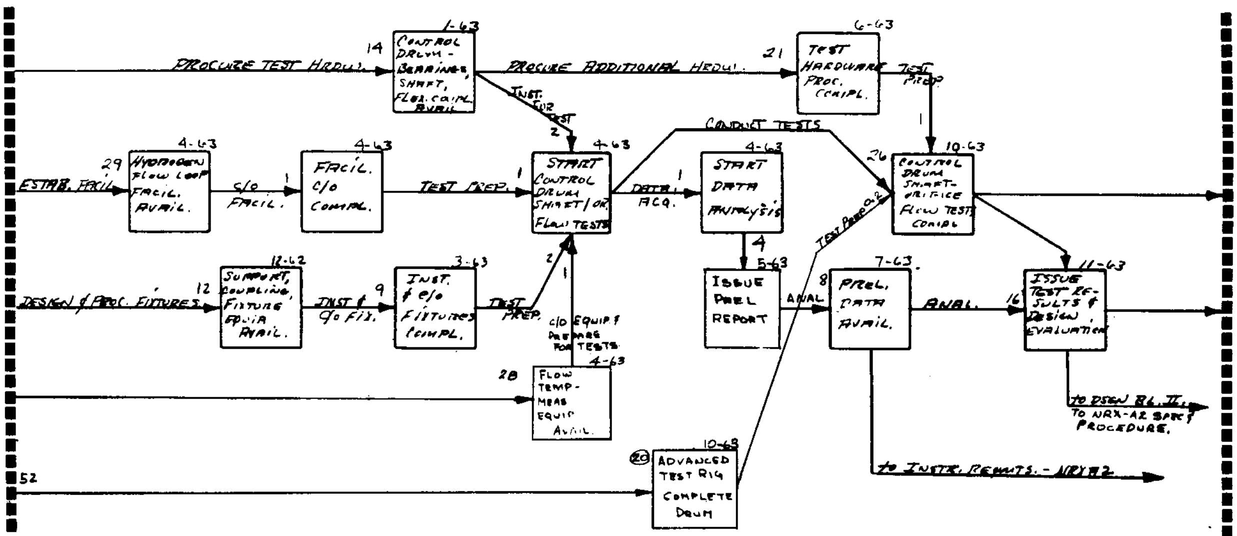
C	=	pressure drop coefficient (dimensionless)
g	=	gravitational constant (ft/sec^2)
ΔP	=	static pressure drop across the component (lbs/ft^2)
ρ	=	density of the working fluid (lbs/ft^3)
V	=	velocity of hydrogen in the component flow restriction. (ft/sec)

Correlations of the pressure loss coefficient with flow parameters and geometry must be established.

6.2 The data will be utilized in establishing design flow areas to give proper cooling to the components in the control drum assembly.

~~CONFIDENTIAL~~
RES[redacted]D DATA
Atom[redacted]

Astronuclear



D.4 - FLOW TESTS OF CONTROL DRUM SHAFT & ORIFICES

D4
4-8-63

~~CONFIDENTIAL~~
RESTRICTED DATA
Atomic Energy Act - 1954

C[redacted]AL
R[redacted]A
A[redacted]

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

E 1 REACTOR ASSEMBLY MECHANICAL TESTS

REVISION NO. 1

1. TEST NUMBER: E 1 DATE: 3/30/63

2. TITLE: REACTOR ASSEMBLY MECHANICAL TESTS

3. PURPOSE:

The KIWI Reactor suffered extensive damage during last hot test run. It has been theorized that excessive vibratory loads may have been one of the primary causes of failure. As a result of this damage the NERVA Reactor has been partially redesigned to better withstand vibration and shock loading. A rigorous analysis of the system can not readily be performed due to non-linear effects and due to the complex configuration. Only through full scale testing under actual boundary conditions can these non-linear effects, caused by friction and by impacting of fuel elements, be studied and evaluated. Laboratory vibration and shock results will be needed to plan hot and cold flow test programs and to interpret data from such tests.

The testing program will be divided into two phases. Phase I tests will provide a background of knowledge which will facilitate further reactor design efforts.

Phase II tests will check the design life of the reactor under laboratory vibration and shock conditions which simulate anticipated environmental conditions of the hot test.

4. REQUIRED DESIGN DATA:

4.1 Phase I Tests

4.1.1 Determine the coupled lateral, torsional and axial modes and resonant frequencies of the reactor core.

Engineer: D. F. Muller

Approved:

[redacted]
[redacted]
[redacted]omic Energy [redacted]

4.1.2 Determine damping for several input levels of vibration in each of the above cases.

4.1.3 Search for resonances which could be damaging.

4.1.4 Measure maximum vibratory stress levels in fuel elements, filler strips and other highly stressed components for various levels of excitation.

4.1.5 Determine the relative motion of fuel elements and filler strips under vibratory loadings.

4.1.6 Determine the behavior of the lateral support and seal components under vibration and shock.

4.1.7 Determine whether "ratcheting" of the inner reflector toward the hold-down springs can occur as a result of friction forces.

4.1.8 Determine any unusual or excessive motions during shock, such as cluster separation, barrel distortion and impact against stops.

4.1.9 Determine stress levels at critical points during shock transients of various levels and durations.

4.1.10 Determine accelerations and relative displacements during shock transients.

4.1.11 Visually observe during inspection any failures that occur during shock.

4.1.12 Determine the directions for which the reactor is most sensitive to shock.

4.1.13 Determine the components most sensitive to shock damage.

4.2 Phase II Tests

4.2.1 Determine the ability of the reactor to withstand sinusoidal levels of vibration simulating anticipated environmental conditions.

4.2.2 Determine the response of the reactor, and life, under random vibration excitation simulating anticipated hot firing and boost-phase flight.

4.2.3 Determine shock response of the reactor under conditions simulating transportation and handling.

4.2.4 Investigate more fully any shock limitations discovered during the Phase I tests.

4.2.5 Determine the basic shock fragility of the reactor.

5. TEST PLAN

5.1 Description

The test plan is as follows:

5.1.1 Phase I Tests

5.1.1.1 Sinusoidal Vibration, Up-firing Position

a. Lateral excitation

b. Torsional excitation

c. Axial excitation

5.1.1.2 Shock Tests

a. Axial up-firing

b. Lateral

5.1.2 Phase II Tests

5.1.2.1 Sinusoidal Vibration

a. Sweep-frequency and resonance dwell tests, up-firing.

b. Sweep-frequency and resonance dwell tests, lateral.

5.1.2.2 Random Vibration

a. Axial up-firing, anticipated spectrum and time.

b. Lateral, anticipated spectrum and time.

The Phase I vibration tests will be run without the outer reflector components and aluminum barrel. This permits simple application of vibratory forces and exposes the transducers for ease of reorientation. The excitation in the lateral and torsional tests is applied directly to the inner reflector. In the axial test the excitation is applied to the dome end support plate. Figures E 1.1, E 1.2 and E 1.3 show the test set-ups. The Phase I shock tests will utilize the outer reflector components with the reactor assembled in a simulated pressure vessel as shown in E 1.4. All Phase II tests will be performed in the same simulated pressure vessel (or an actual one if available). If observation of data during the tests indicates component failure, the reactor will be disassembled. Components will be inspected for damage, causes of failure determined, and defective parts replaced. .

5.2 Components Under Test

The Phase I tests will utilize the ND 201 reactor which contains a full Oak Ridge graphite core and prototype components where possible. Phase II tests will be performed on the ND 207 reactor, which is a more accurate simulation of the NRX A-1. Both the ND 201 and ND 207 reactors have been released for procurement by the Reactor Mechanical Design Section.

5.3 Experimental Set-Up

The 5000 lb. vibration exciter and sand-drop shock machines at WANL will be used for Phase I tests. Instrumentation and recording systems as listed below will be used. The Phase II tests utilize a large vibration exciter system capable of over 30,000 lbs. force, applied in either a sinusoidal or random manner. This facility is being planned by WANL

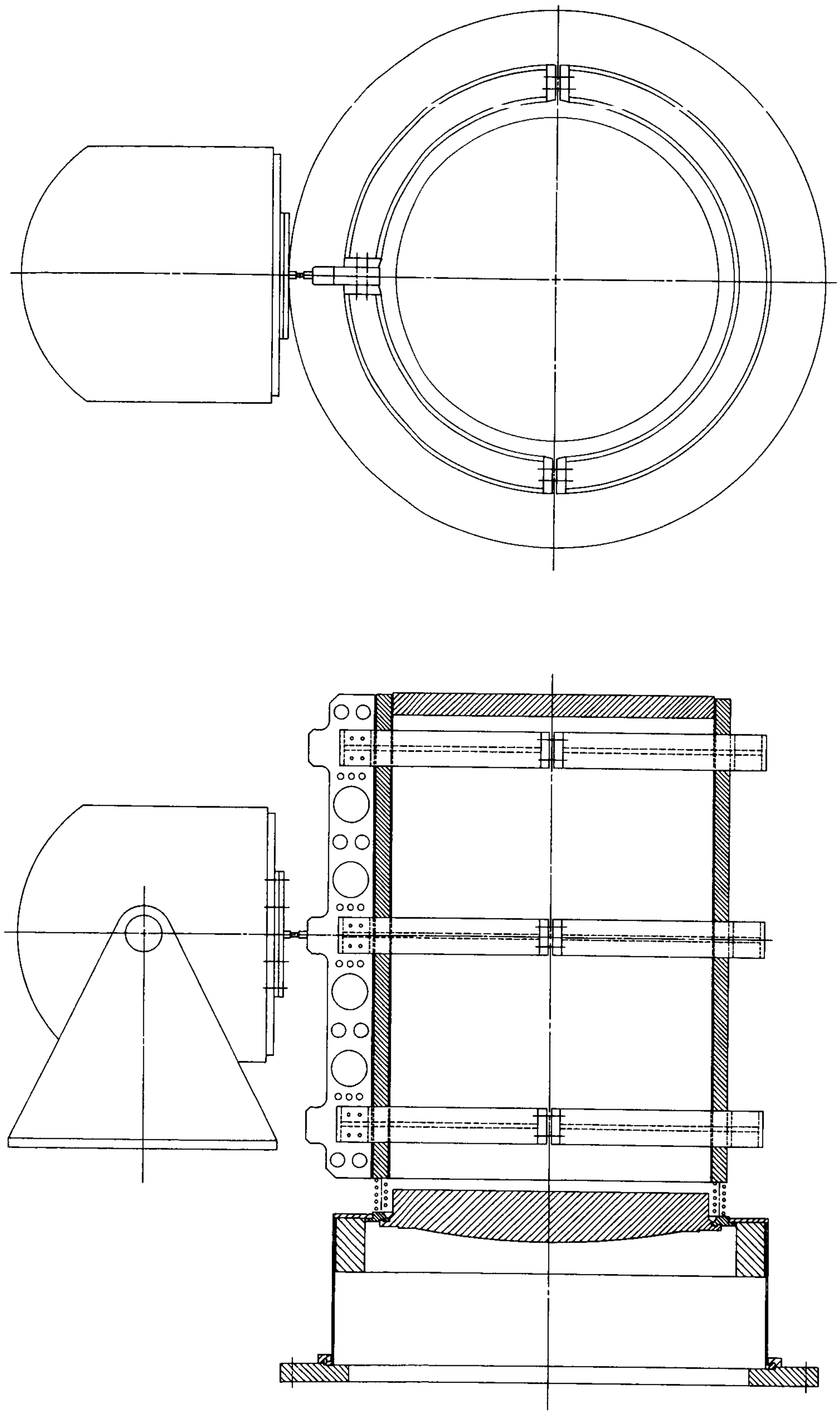


Figure E 1-1 Reactor Assembly ND 201 Lateral Vibration

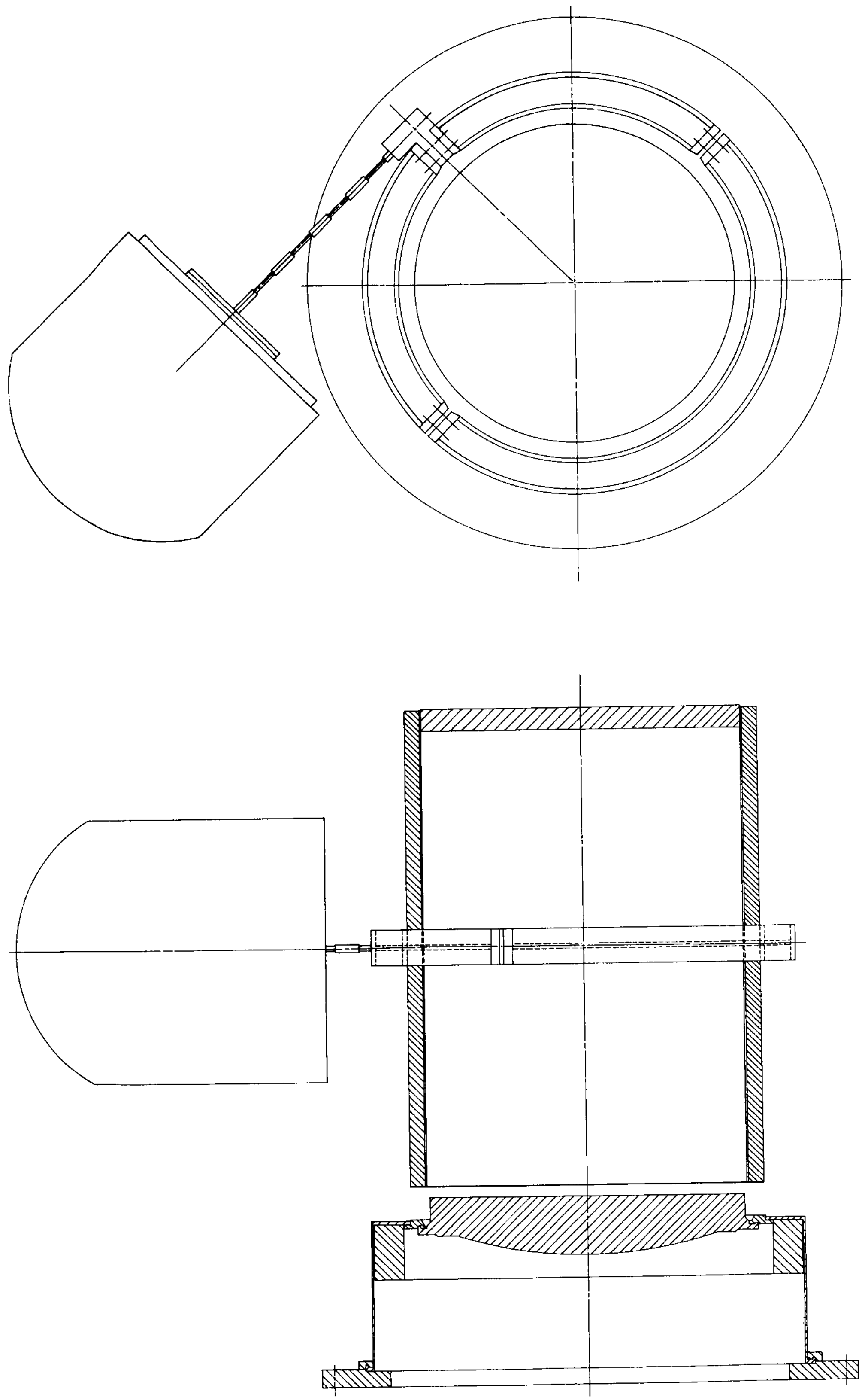


Figure E 1-2 Reactor Assembly ND 201 Torsional Vibration

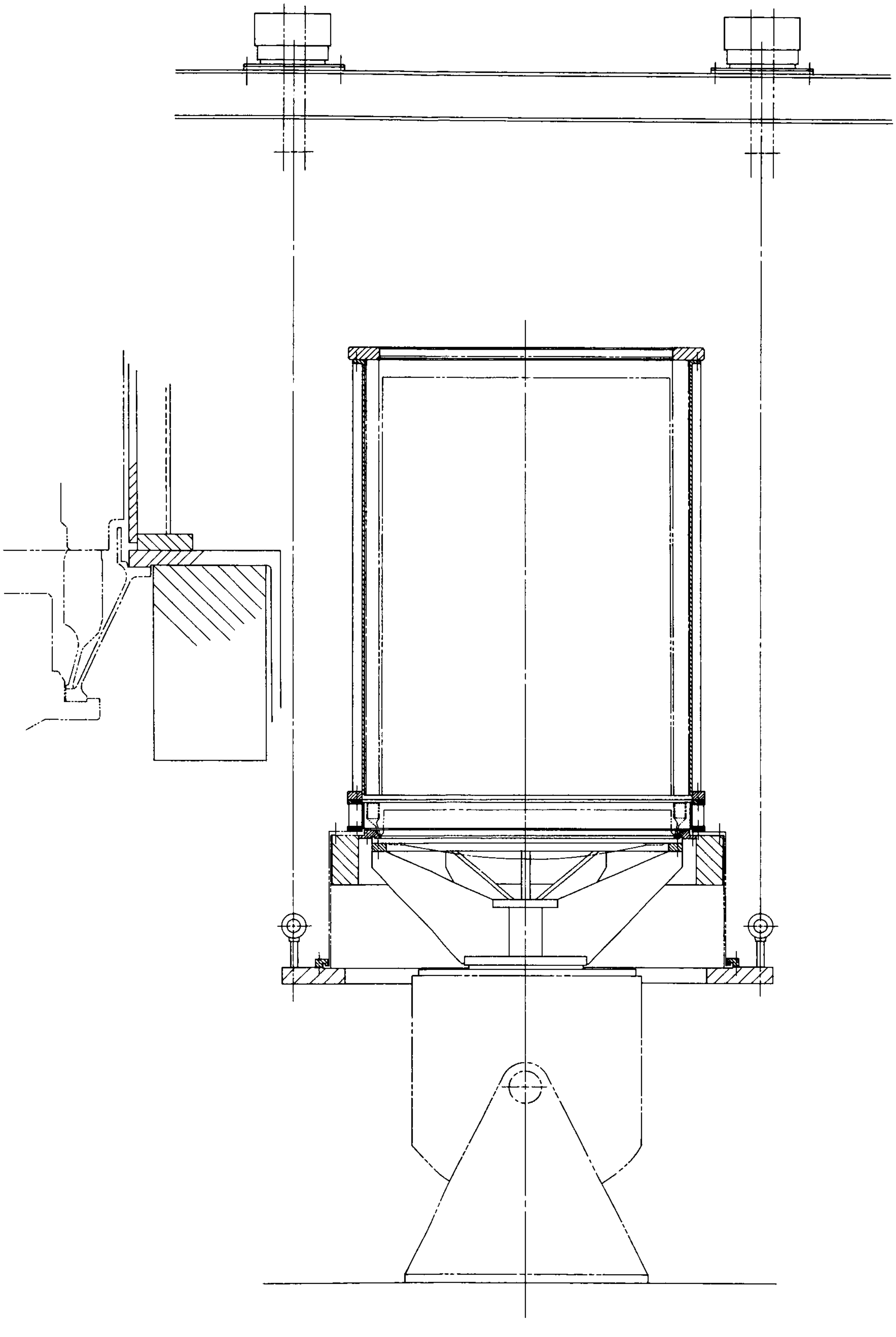


Figure E 1-3 Reactor Assembly ND 201 Axial Vibration Test

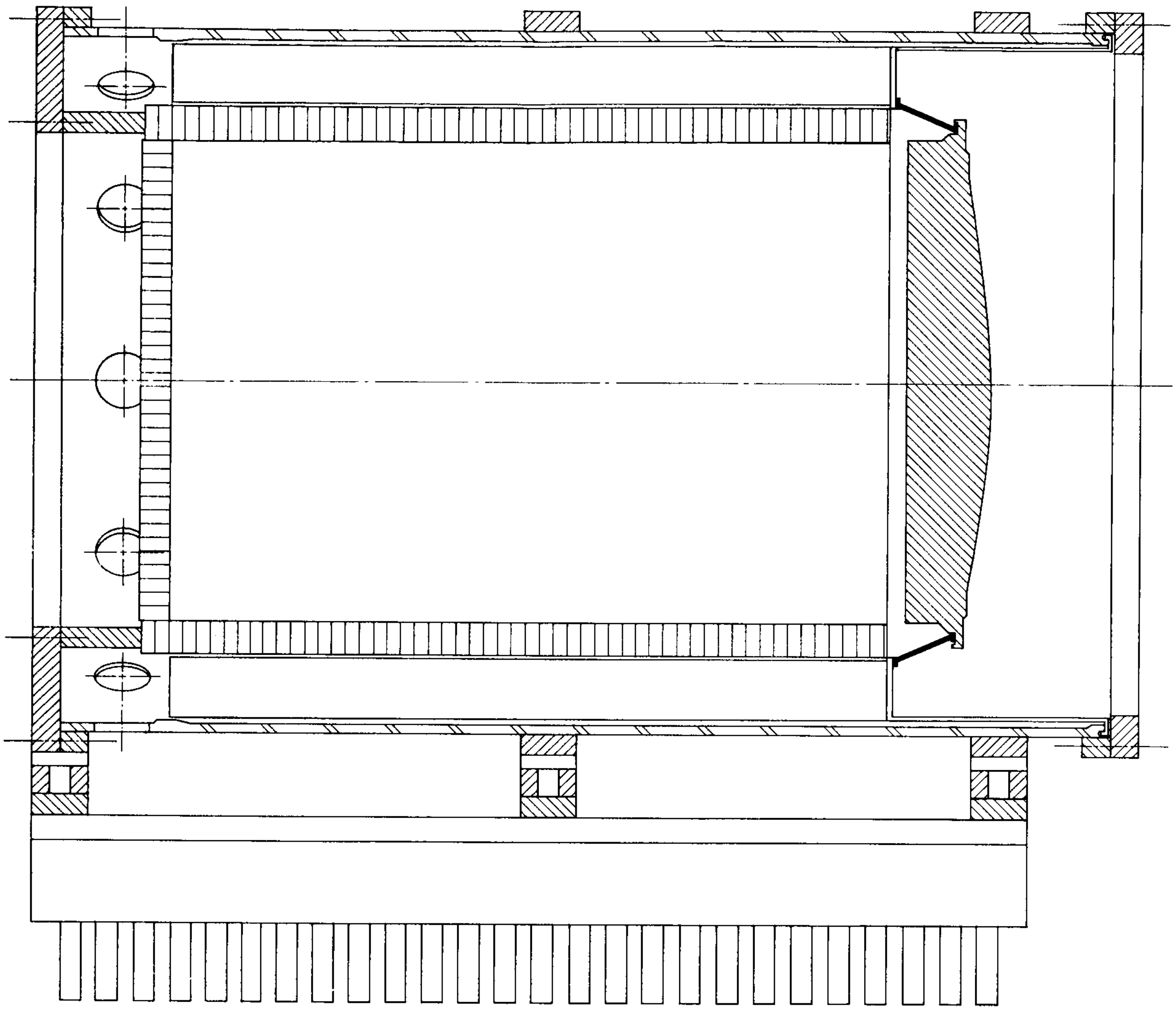


Figure E 1-4 Reactor Assembly ND 201 Shock Test for these tests and future reactor vibration tests. It is necessary that the vibration facilities be located near the assembly areas so that possible shipment damage and transit time will be minimized.

5.4 Test Parameters

5.4.1 Independent Variables

Phase I Sinusoidal Vibration Level - 0.- 5 "G"

Phase II Sinusoidal Vibration Sweep Level - Programmed to simulate anticipated enviroment.

Phase I Sinusoidal Vibration Frequency Range - 5 - 500 cps.

Phase II Sinusoidal Vibration Frequency Range - 5 - 2000 cps.

Shock Deceleration and Shock Duration - Current Design Spec.

Phase II Random Vibration Spectrum and Duration - Determined from anticipated environment on hot test.

Pressure - Ambient

Temperature - Ambient

5.4.2 Dependent Variables

Acceleration response curves of input and output points.

Resonant frequencies.

Input impedance curves.

Wave shape data.

Relative displacement of core with inner reflector.

Relative displacement of inner reflector with pressure vessel.

Relative displacement of adjacent filler strips.

Relative displacement of seals with inner reflector.

Relative displacement between clusters.

Stress levels in fuel elements.

Stress levels in filler strips.

Stress levels in tie rods.

Stress levels in lateral support leaf springs.

Stress levels in inner reflector.

Damping of important modes of vibration.

Acceleration vs. time curves for shock input.

Shock input and output point spectrums.

Relative displacement vs. time curves for components.

Stress vs. time curves for components.

5.5 Instrumentation and Data Acquisition

Accelerometer, strain gage, force transducer and displacement transducer channels will be used in obtaining the required data. In addition the nozzle end of the reactor will be observed both stroboscopically and with a high speed motion picture camera.

Displacement transducers will be used to sense motions of the core support blocks, the inner reflector, the outer reflector and the dome support plate. Any relative motion between clusters will be sensed by displacement transducers located as triads between three adjacent support blocks. Accelerometers will be placed at each end of the core, on the inner and outer reflectors and on the dome support plate with sensitive axis oriented in the proper direction for the test being run. Strain gage instrumentation to measure stress levels and mode shapes will be placed at critical points throughout the reactor. Of particular concern will be the fuel elements, filler strips, tie rods, lateral support springs and inner reflector. Specific location for these gages has already been determined. Force transducers will be used to obtain input impedance curves for the reactor. The details of cluster separation, if it occurs, will be observed using the motion picture camera and stroboscope located at the nozzle end.

Certain transducers will be identified and monitored by the oscillograph at all times. In the vibration tests, the transducers will be recorded on magnetic tape during sweep frequency runs and at each resonant frequency. Groups of transducers will be read out sequentially at each test condition. The magnetic tape records will be analyzed after the tests have been completed.

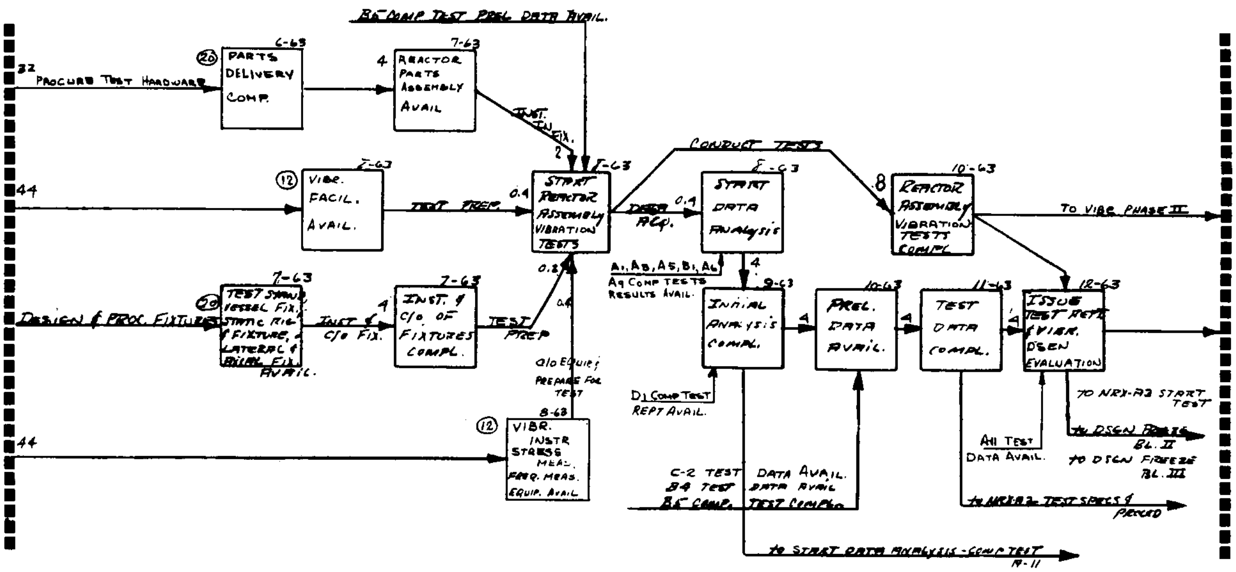
6. ANALYSIS AND DATA UTILIZATION

Dynamic analysis of the reactor test assemblies will be performed. Experimental results will confirm the adequacy of the theoretical models, permitting analysis of reactors with other design changes. The determination of response data (transfer functions) is necessary to interpret the self-induced vibration behavior of cold flow tests and hot runs. Sinusoidal frequencies appearing in the flow tests will be correlated with the resonant frequency data obtained in this test series. Stress level measurements will enable estimates of core life under vibratory and shock conditions. Fatigue and stress-strain data from the component test program will be used to obtain these results.

Shock spectrums for the input and core motions will be computed from the shock data. Shock spectrums are necessary to estimate damage and for comparison with spectrums of actual environments. The shock tests will determine safe levels of shock exposure and will determine improperly designed components. It is necessary that this data be obtained early in the program to avoid later costly and time consuming redesign. All component and sub-assembly failures will be analyzed as to mode of failure. The damaging potential of resonances is related to the magnitude of the damping. The values of damping obtained in these tests will determine the suitability of the design.

Successful bundling of the core depends upon the ability to maintain suitable pressure between core and support blocks under all conditions of vibration and shock. This bundling ability will be determined by the relative displacement measurements of the test series.

Astronuclear



E 1 - REACTOR ASSEMBLY MECHANICAL TESTS

E1
4-8-63

Astronuclear

WANL-TNR-095

TEST SPECIFICATION

E 2 FLOW DISTRIBUTION SCALE MODEL

REVISION NO. 1

1. TEST NUMBER: E 2 DATE: 3/30/63

2. TITLE: FLOW DISTRIBUTION SCALE MODEL

3. PURPOSE:

To achieve the optimum performance from the reactor and the highest degree of reliability, the reactor must operate at design conditions. Tests of individual components are necessary, but not sufficient, to qualitatively evaluate their performance and therefore, a complete model must be built, tested and measurements taken to determine the interaction of the components. Correct flow distribution throughout the reactor is required in order to achieve maximum power output and avoid temperature damage and failure of the NRX-A hot test.

4. REQUIRED DESIGN AND CALIBRATION DATA:

4.1 Estimate the degree to which the components (from the inlet to the reflector to the outlet of the core) attenuate or amplify inlet flow maldistributions.

4.2 Indicate the modifications necessary in component design such that the flow mal-distribution are attenuated to an accepted level.

4.3 Evaluate plenum effects on core inlet flow distribution.

4.4 Determine the component or components which greatly affect the overall system performance and thus provide information on areas which require further design and testing.

Engineer: V. R. Amatangelo

Approved: E. A. De Zubay

4.5 Determine the relative effects of component assemblies displacements on flow distribution.

5. TEST PLAN:

5.1 Description - A model of one fifth scale of the entire NRX assembly will be used to experimentally investigate the flow distribution. The model will be constructed of plexiglas, thus providing for visual observation of the interior of the components and of the core. Tests will be conducted using air and/or water as the working fluid and various tracer techniques (titanium tetrachloride, helium gas, etc.) will be employed to observe flow mixing and flow trends. Initial tests will be conducted under idealized and uniform inlet flow conditions and then, deliberately, introducing progressively larger inlet maldistributions and measuring their effect (attenuation or amplification) at the core inlet. A change in design can be quickly incorporated in the model and an evaluation of component performance and system performance can be quickly accomplished.

5.2 Components Under Test - The test fixture will simulate the entire reactor to a one fifth scale linear dimension. Due to the scaling down of the components, various machining and component simulation problems will develop. The model will include the following components and assemblies:

5.2.1 Inlet Plenum Chamber

5.2.2 Inner Reflector

5.2.3 Outer Reflector

5.2.4 Control Drums

5.2.5 Shield

5.2.6 Screen Support Plate with Screen

5.2.7 Dome End Support Plate

5.2.8 Fuel Element Clusters

5.2.9 Pressure Vessel

5.3 Experimental Set-Up - The test apparatus consists of the air supply, pressure reducing valve, various flow control valves, flow orifices, the test assembly, flow control valve and flow measuring orifice. Flow enters the reflector inlet plenum which is equipped with suitable pressure taps, and passes through the simulated components which exist around the circumference of the core. After passing through the shield, screen, dome end core support plate and core, the flow will exhaust through a simulated nozzle. The pressure and flow distributions through these components will be observed, measured, and varied.

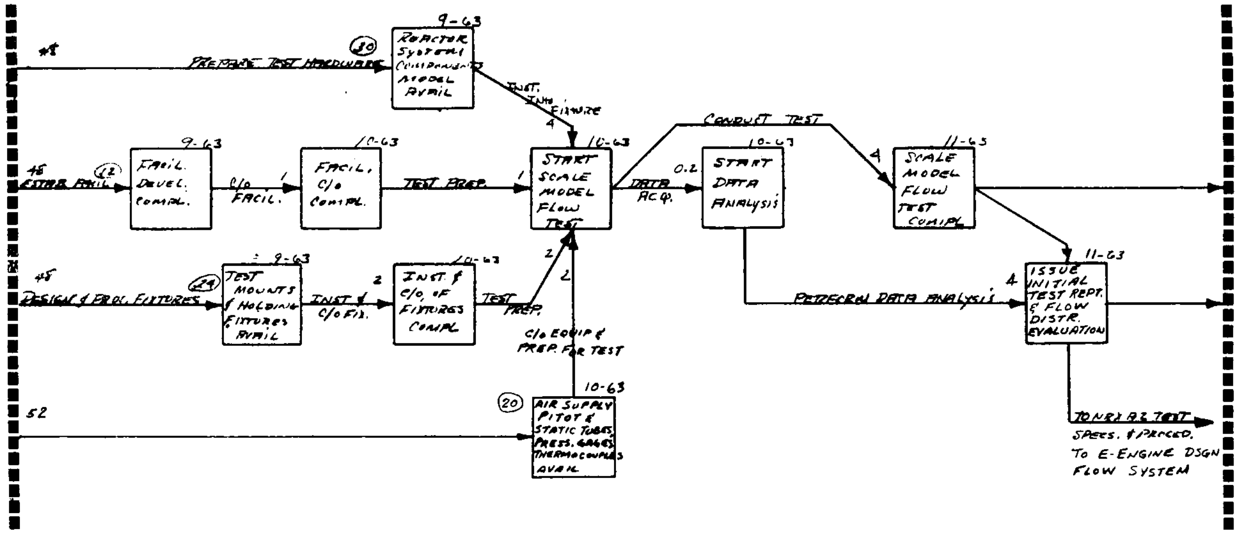
5.4 Test Parameters - (Range to be Determined)

- Inlet Pressure
- Mass Flow
- Pressure Distribution
- Flow Distribution
- Flow Passage Size
- Geometry

5.5 Instrumentation and Data Acquisition - Tests will be conducted at steady state conditions. Pressure, pressure distributions and pressure drops will be measured by means of manometers. Flow will be measured by means of precision calibrated orifices. Flow distribution will be traced and observed using titanium tetrachloride or some similar smoke producing agent for air, and dyes for water.

6. ANALYSIS AND DATA UTILIZATION:

The results of these tests will indicate the component or components which may attenuate or amplify inlet flow maldistributions. Changes will be incorporated into the model to correct or minimize the maldistribution.



E 2 - FLOW DISTRIBUTION SCALE MODEL

E2
4-8-63